

PROGRAMMING FOR A DIGITAL
COMPUTER CONTROL SYSTEM

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PROGRAMMING FOR A DIGITAL
COMPUTER CONTROL SYSTEM

by

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PREFACE

The work described herein was done at the Research and Development Laboratories, Hughes Aircraft Company, Culver City, California, during the industrial term of the Electronics Engineering curriculum. My control system project was suggested by the Laboratories, and was carried out with their fullest cooperation as a part of a large scale study of airborne digital control systems.

I shall assume that the reader is conversant with current terminology in the computer field (2). What few terms are not in general use I will explain. The words "order" and "instruction" are synonymous.

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I. INTRODUCTION

This thesis describes in detail a program and coding for a particular aircraft navigation display control system utilizing a digital computer, in less detail the equipment used, and finally a number of suggestions for programming of control systems.

Some modern control systems become very complex and require many individual computing or compensating elements. It seems likely that a gain might be achieved by combining all these computing and compensating functions in one elaborate general-purpose computer, perhaps on a time sharing basis (1). Either digital or analog techniques could be used.

A digital computer offers certain inherent advantages in this application. Chief among these are, first, that changes in function of parts of the control system, such as adjusting compensation of a servo loop, are made simply as changes of numbers or instructions within the computer. No change of physical equipment is needed. Second, and more basic, is the memory, or storage of information that a digital computer contains. Thus, the control system can be influenced by its past performance, or by outside stimulation. Take, for example, an automatic factory. Then the output of the factory could be influenced by inventories and sales records which had been gathered and collated by itself.

Such an elaborate control problem is presented in some high-performance aircraft, and the computer on which the described program was

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run was a digital computer for airborne use (3).

Programming and coding a problem for a digital computer have received much attention (4), but the approach has been one of reducing to a minimum the human labor, either by admittedly inefficient computations (5,pg.115) or by making the machine do the work of coding (6). This approach leads to overall efficiency when a problem is done once or a few times. If, however, a problem is repeated ad infinitum, as in a control system, human planning time starts to pay off as reduced physical equipment due to the lessened storage capacity needed for the more efficient set of instructions. This will be discussed later.

In any machine that is very complicated some means of diagnostic testing should be provided. This will be elaborated..

Finally, a reasonably didactic description of the program will be given. This program was a first attempt, and it is on the basis of the mistakes made that the recommendations have been formulated.

1. The first part of the report is a general introduction to the subject.

2. The second part is a detailed description of the methods used in the study.

3. The third part is a discussion of the results of the study.

4. The fourth part is a conclusion and a list of references.

5. The fifth part is a list of the names of the authors and their institutions.

6. The sixth part is a list of the titles of the papers included in the volume.

7. The seventh part is a list of the names of the editors and the publisher.

8. The eighth part is a list of the names of the reviewers and the date of the review.

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CHAPTER I. DESCRIPTION OF EQUIPMENT

The equipment used, while not the subject of this thesis, did influence the programming and coding, and so should be described. Peculiarities of the computer logic important to the program will be described in later chapters when applicable.

The computer used was a first model which had been used for some time for circuit and component reliability and logical checks. No input-output equipment had been designed specifically for it, although input-output equipment was available that had been used on a very similar computer. One function of the Control Box (Chap. II) was to adapt and interconnect the computer and the input-output equipment. The Brown Teleplotter was used intact except for changes in its internal servo system to respond to dc signals of the desired amplitude.

The computer is of the general purpose, serial, binary digital type (3). It has an arithmetic unit, a control unit, and a magnetic drum memory unit. The arithmetic unit performs the arithmetic operations of addition, subtraction, multiplication and division. The unit consists of three one word circulating registers and a binary adder. The magnetic drum memory (3) provides one eight word circulating register, the "d" register, and fourteen sixty four word storage bands. These bands are interpreted by the control unit as eight order bands containing instructions, and six number bands. One of the number bands and one of the order bands are tied together, so that an instruction can be interpreted as a number and changed, written back into the memory, and then used as a new instruction. Such changes are made as

1. The first part of the document is a letter from the President of the United States to the Congress, dated January 3, 1862. The letter is addressed to the Senate and the House of Representatives, and is signed by Abraham Lincoln. The letter is a copy of the original, and is in the handwriting of the President. The letter is a copy of the original, and is in the handwriting of the President.

2. The second part of the document is a letter from the Secretary of the War Department to the Secretary of the Navy, dated January 3, 1862. The letter is addressed to the Secretary of the Navy, and is signed by the Secretary of the War Department. The letter is a copy of the original, and is in the handwriting of the Secretary of the War Department.

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the result of the computations in progress. The instructions available to the coder are shown in Table II.

The input-output equipment converts analog information (dc voltages) into an equivalent binary number at a sampling rate of once every fourteen magnetic drum revolutions, writes the most recently sampled binary number onto the drum, reads the most recently written output binary number (written by the computer) and converts it to an equivalent analog quantity (dc voltage). It is multichannel, having nine inputs and four outputs, with one calibrating period (7).

The plotting board consists of a chart and pen so arranged that two input dc voltages are interpreted and plotted as x and y deflections of the pen on the chart. A potentiometer error detector feeds a modulator, whose ac output is proportional to the error. An amplifier then drives a motor in such a direction as to tend to make the error zero. This is duplicated for the two axes. The speed of response of the pen is much faster than the contemplated plotting speed.

CHAPTER II. THE PROBLEM AND ITS PROGRAMMING.

1. The Problem

A navigation display was desired to demonstrate the ability of the Hughes Model I digital computer to store much information for a long time. The operation of the device was visualized as follows. First, a map of the desired track is placed on a plotting board containing a movable plotting pen. The pen is placed in turn over the departure point and each of the enroute way points, or "fixes". At each point a button is depressed which will enter the position into the memory of the computer. After all points are entered, the pen is returned to the departure point and the computations started by throwing a switch. The pen then "flies" to each of the fixes in turn at a fixed ground speed on straight line courses. After getting to the last fix, or destination, the computer would turn itself off after preparing the program for entering the next set of fixes. Provision was made for entering sixteen fix positions. A signal light would indicate when the computer was ready to have fixes entered, or ready to fly.

The Control Box had the following operational controls: two handwheels for East-West and North-South positioning of the pen during the entry portion of operation, a pushbutton for entering fixes and starting fly operation when ready, a function switch with Enter and Fly positions, and a switch to turn on recording pen on plotting board to

prevent smearing. Contained in the same box were various interconnections between the computer, the input-output equipment, and the plotting board, various disconnect switches for the power and timing pulses, and reading and writing amplifiers required by the input-output equipment. A schematic of this box is included as Figure 1 to indicate the functions, although the details are immaterial to this thesis.

It was desired to make the fly routine a feedback loop so that the present position of the pen could be sensed in the computations, and so that smoothing could be included by placing a low pass filter after the dc analog output. Smoothing could have been done in the program, and probably will be included at a later date by Hughes engineers. Smoothing in the program would insure, for example, that computational errors of a random nature would be smoothed out of the output, rather than being cumulative. Smoothing in the dc analog output will accomplish the same result, but requires additional equipment. Smoothing should not be confused with the essential filter required to smooth the sampling rate.

In the course of the fly computations, the present position is written into the memory by the input equipment. The computer then reads this position and compares it with the fix position to which the "plane" is now headed. By a trigonometric method involving the fixed speed towards the fix position, an incremental change in position for

the computing period is determined and added to the present position to give a future position. This future position is then fed to the output equipment, through the low pass filter, and to the pen to position it. This future position then becomes the present position for the next computation. The computations are repeated every 14 drum revolutions or 0.1 seconds, i.e., the sampling rate is ten cps. Note that if a computational error is made and the plane gets off course, it will still continue to fly to the fix on the nearest straight line course. When the plane arrives at the desired fix, the computer will change its instructions so that the next fix position will be used. After getting to the sixteenth fix position the computer will stop, after setting in the proper instructions to enter new fixes.

2. The Equations

The course and incremental position are computed by the following set of equations.

- Let x, y be the coordinates of the present position.
- x_p, y_p be the coordinates of the next fix position.
- dt be the sampling period, 0.1 second.
- dx, dy be the coordinate distances travelled in time dt .
- V be the specified ground speed towards the next fix.
- θ be the angle of direction of travel, measured from the x axis.

Then we can say that

$$\frac{y_p - y}{x_p - x} = \tan \theta = dy/dx.$$

$$\cos \theta = 1 / \sqrt{1 + \tan^2 \theta}.$$

$$dx = V dt \cos \theta.$$

$$dy = dx \tan \theta.$$

$$x_{n+1} = x_n + dx.$$

$y_{n+1} = y_n + dy.$ These last two are the future position, and become x, y for the next period.

Difficulties arise from two sources. (1) Ambiguities due to sign of $\tan \theta$, and (2), the fact that the computer can handle only numbers whose magnitude is less than one. These will be taken care of by using the conditional transfer ckS instruction. (Table II). Note that no instruction is provided to specifically handle square roots, so an approximation will have to be made for $\cos \theta$.

The equations finally used that follow, resolve these difficulties. See fig. 2.

Given $x, y, x_p, V dt, Z.$

- | | |
|---|--|
| 1. Find $ X_p - X .$ | |
| 2. Find $ Y_p - Y .$ | |
| 3. Find $ X_p - X \neq Y_p - Y .$ Store for future use. | |
| 4. Find $ X_p - X = Y_p - Y .$ Check sign. If | |
| 5a. Positive. Find | 5b. Negative. Find |
| $(Y_p - Y)/(X_p - X) = \tan \theta.$ | $(X_p - X)/(Y_p - Y) = \cot \theta.$ |
| 6a. Approximate $\cos \theta$ by polynomial. | 6b. Approximate $\cos \theta$ by polynomial. |
| 7a. Multiply $V dt \cos \theta = dx.$ | 7b. Multiply $V dt \cos \theta = dx.$ |

- | | | |
|--|--|--------------------------------------|
| 8a. Multiply $dx \tan \theta = dy$. | | 8b. Divide $dx / \cot \theta = dy$. |
| 9. Divide $dx / (X_p - X)$. Check sign. If | | |
| 10a. Positive. Do nothing. | | 10b. Negative. Subtract |
| $dx = dx^*$. | | $0 - dx = dx^*$. |
| 11. Divide $dy / (Y_p - Y)$. Check sign. If | | |
| 12a. Positive. Do nothing | | 12b. Negative. Subtract |
| $dy = dy^*$. | | $0 - dy = dy^*$. |
| 13. Add $X \neq dx^* = X_{n+1}$.. Write as output. | | |
| 14. Add $Y \neq dy^* = Y_{n+1}$.. Write as output. | | |
| 15. Subtract $(X_p - X \neq Y_p - Y) - z$. Check sign. If | | |
| 16a. Positive. Start over | | 16b. Negative. Start over |
| with same X_p, Y_p . | | with new $X_p + 1, Y_p + 1$. |
| 17. Count up a number such that after executing 16b sixteen times, | | |
| a change of sign occurs to stop computer. | | |

In the above, step 4 determines whether $\tan \theta$ is going to be greater than one. If so, $\cot \theta$ is used. Steps 9 and 11 insure that dx and dy are of the proper sign. Step 15 checks how closely the plane is to the fix position. When this distance, or rather a distance which is slightly greater than the distance to the fix, becomes less than some small number z , the plane has arrived, and the next fix position is used.

The polynomial used to approximate $\cos \theta$ from $\tan \theta$ or $\cot \theta$ is derived by a Chebyshev polynomial operation, and is accurate to 0.3%

1. The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that proper record-keeping is essential for the transparency and accountability of the organization. This section also outlines the various methods used to collect and analyze data, ensuring that the information is reliable and up-to-date.

2. The second part of the document focuses on the implementation of the proposed changes. It details the steps involved in the rollout process, from initial planning to final execution. This section also addresses potential challenges and provides strategies to overcome them, ensuring a smooth transition to the new system.

3. The third part of the document discusses the ongoing monitoring and evaluation of the project. It highlights the need for continuous communication and collaboration between all stakeholders involved. This section also provides a timeline for the project, with key milestones and deadlines clearly defined.

4. The fourth part of the document concludes with a summary of the findings and recommendations. It reiterates the importance of the project and the need for continued support and resources. This section also provides a final overview of the project's goals and objectives, ensuring that all parties are aligned and committed to the success of the initiative.

within the range used:

$$\cos\theta = 0.1474x^4 - 0.4340x^2 + 0.9965, \text{ where } x = \tan\theta, \text{ or}$$

$$\cos\theta = y(.1474y^4 - .4340y^2 + 0.9965), \text{ where } y = \cot\theta.$$

This approximation is easily done on the computer, and is easier than conventional algebraic methods would be.

3. The Fly Program

Using the instructions contained in Table II and these equations for a guide, the program was designed and is presented in Table IV. Table III shows a flow diagram of the instruction sequence. Before detailing the instructions some general explanations are required.

On a machine which has available only such unsophisticated instructions as shown in Table II, the detailed coding must proceed closely with the program, since the order in which operations are performed depends upon, for example, when certain numbers become available from the memory. It may be advantageous to delay some operations till a more convenient time. Thus the sequence of instructions may seem odd until the coding is studied in Chapter III.

The subscript on instructions involving the D register denotes the sector number in this eight word memory.

The B register acts as an accumulator for the arithmetic unit; that is, any number written into the B register adds algebraically to the number already there. In starting a new operation it is necessary to insure that the B register is cleared, as in instruction # 1.

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2. The second part of the document focuses on the financial aspects of the organization. It provides a detailed overview of the budget, including the projected income and expenses for the upcoming year. This section also discusses the various financial risks and how they are being managed to ensure the organization's financial stability.

3. The third part of the document addresses the operational aspects of the organization. It describes the various processes and procedures that are in place to ensure the efficient and effective delivery of services. This section also discusses the various challenges that the organization is facing and how they are being addressed.

4. The fourth part of the document discusses the human resources aspect of the organization. It provides an overview of the current staff levels and the various roles and responsibilities of the different departments. This section also discusses the various training and development programs that are in place to ensure that the staff is equipped with the necessary skills and knowledge to perform their duties effectively.

5. The fifth part of the document discusses the legal and regulatory aspects of the organization. It provides an overview of the various laws and regulations that the organization is subject to and how they are being complied with. This section also discusses the various legal risks and how they are being managed to ensure the organization's legal compliance.

6. The sixth part of the document discusses the environmental and social aspects of the organization. It provides an overview of the various environmental and social issues that the organization is facing and how they are being addressed. This section also discusses the various initiatives that are in place to promote sustainability and social responsibility.

7. The seventh part of the document discusses the future of the organization. It provides an overview of the various strategic initiatives that are in place to ensure the organization's long-term success. This section also discusses the various challenges that the organization is facing and how they are being addressed.

8. The eighth part of the document discusses the conclusion of the document. It summarizes the key findings of the document and provides a final overview of the organization's current status and future prospects.

Any instruction involving "from B", such as ba, bm, etc., will clear the B register.

All other registers and the memory will hold a number until a new number is written over it, replacing the old number with the new number.

Instruction #1 will be called simply #1, etc.

#1 clears the B register.

#2 transfers the fix X_p to the D register. This instruction will have to be changed as we progress from fix to fix. #3 does same for Y_p , but will be a series of instructions, as will be seen in Chapter III.

#7 and #8 bring in the uncorrected values of present position, x_0 and y_0 , from the memory. These numbers are then divided by a scale factor (7) to become the corrected x and y, and are stored in D (up to #17).

#18 to #38 are manipulations to obtain K'/L' , which is a rough measure of the distance to go to the fix, see Figure 2. Some intermediate results are stored in D for future use.

The quantity K'/L' can be a number from 0 to 2. This computer, which is designed to handle numbers between -1 and 1 (modulo 2), interprets a number between 1 and 2 as a negative number. Thus #39 checks this fact, and if negative, indicating that K'/L' is greater than 1, writes in its place an arbitrary positive number, $\frac{1}{4}$.

#44 to #49 form $K'-L'$ as a measure of the octant of θ . If in an

octant such that $\tan \theta$ is less than 1, the computations use $\tan \theta$. If $\tan \theta$ is greater than 1, the computations use $\cot \theta$. This avoids overflow on the following division. #50 senses this fact.

#51 to #54 form $\tan \theta$, OR #73 to #76 form $\cot \theta$.

Whichever form is used, #55 to #72 form either $\cos \theta$ or $\cos \theta / \cot \theta$ by the approximation shown on page 10.

#78 and #79 bring K'-L' into the A register again to check sign. This was an easier operation to code than to store the actual decision, #50, previously made, i.e., the decision was made twice.

#81 to #93 form dx and dy for the case when $\cot \theta$ is used. The sign of dx and dy may be wrong.

#94 to #102 form dy and dx for the case when $\tan \theta$ is used. Again, the sign may be wrong.

#103 to #118 check that dx is in the same direction (has same sign) as x coordinate distance to the fix. If wrong, the sign is changed by subtracting from zero.

#119 to #137 does same for dy. Note again that a definite possibility for overflow exists in the two divisions, which are used to check parity of sign, when the present position approaches a fix. dx and dy must be larger than the actual change in present position due to the time lag effect of the smoothing filter. This mistake was corrected by utilizing a multiplication to check parity of sign in the actual machine, but was left in this program to illustrate that not only must

you think in the language of the computer, but also in terms of the overall machine considered as a control system, i.e., its analog aspects.

#138 to #149 form the future position and write this position into the memory in a position where the output conversion device can read it.

#150 to #154 compare K'/L' , or roughly distance to fix, with a small arbitrary number, z . When the pen has approached within z of the fix position #155 senses this change of sign. If not within z of fix, several waits are necessary so that recycling back to the #1 start of the program will be after the 14th revolution of the magnetic drum. This is to insure synchronism with the sampling rate of the input-output equipment.

If within z of fix, #160 to #165 take #2, add a number to the instruction such that the "words to wait" (see Chapter III) are changed to give a new X_p and Y_p , and write the new #2 back in position so that it can be used the next time around. Each time a fix is changed a number is added to the count number such that after the sixteenth fix is passed the count number becomes greater than 1, overflows, and appears as a negative number to #175. #179 then writes 0 in output 4, which is connected through the output device to a signal lamp, putting out the lamp. Later we will see that the lamp had been put on after the

last fix was entered. #180 to #182 write in #2 of Table V, the entry program (see next section), so that the instructions will be correct for its initiation.

#183 uses the same order as some number not zero so that #184 will stop the computer after getting to the sixteenth fix, or the destination.

4. The Entry Program

In Table V are the instructions used to enter fixes into the memory.

#2 to #6 change the "words to wait" in the same manner as in previous section. Since this operation is done before using the order, the first "old am instruction" will be some number, meaningless as an instruction, which when added to will be the desired "new am instruction". This will be discussed further in Chapter III.

#7 to #16 alter present position, which in this case is the desired fix to be entered, by the same scale change as in previous section.

#17 is an example of programming influenced by the coding requirements. It was necessary to enter this number into the same position in the memory as the "old am instruction" had been. This required sixty four word times, and so the intervening time might as well be used for some more useful purpose.

#21 makes use of the number written by #17 as an instruction, and enters the fix position into the memory.

Since the instruction following #22 must occur immediately after writing the fix position (See Chapter III), and the fix positions are in separate places in the memory, #23 becomes a series of identical instructions, but with different "words to wait". This provides a means of determining when the sixteenth and last fix has been entered without utilizing a count number as was done in the previous section. The last of this series is called #28.

For the first fifteen points, then, #23 to #27 puts an arbitrary positive number in to B, a zero into output 4 for the signal light, and stops the computer ready for the next fix to be entered.

#28 to #35 writes the instruction which becomes #2 of the fly program in its proper place, writes a number which is nearly full scale into output 4 to light signal light, writes a zero in the count number used in the fly program, and stops the computer ready for flying.

5. The Test Program

The test program shown in Table I was included for diagnostic testing of the computer components. It was of a type used previously for testing the Model I computer, and performs the arithmetic functions, various transfers, and utilizes all the number and order bands of the memory. It does these operations on all binary numbers from 2^{-7} to $1-2^{-7}$.

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This program is not explained in detail since it is not the writers work, and is immaterial to this control system, except in its operational use.

CHAPTER III. CODING THE PROBLEM

Coding the program developed in Chapter II requires a detailed knowledge of the computer and how instructions follow one another. Table I, contained in the envelope in the back of the thesis, lists the coded problem. Programming and coding were done nearly simultaneously.

Three separate problems are coded in Table I: the fly program whose instructions are labelled F, the entry program labelled E, and the test program labelled T. The instructions in each of the three are serially numbered whenever possible. Table III shows a flow diagram of instructions for the fly program. Reference should be made to Tables IV and V for the sense behind the coding.

The Model I computer uses a relative address code (3) in which the address of the next instruction is given by specifying the memory band in which the instruction occurs, and the number of word times till the new instruction is ready to be read. The system is relative because the sector address of an instruction (or number) is never given, except for the first of a series of instructions, which always is in sector 1 in the selected memory band. (The m^{th} sector is the m^{th} word after the arbitrarily designated sector 64 in memory).

An example will follow to illustrate this point. First, the "book-keeping" shorthand should be explained. The instruction itself is follow-

ed by a series of three numbers in Table I. The first is the words to wait after reading the order, and before executing the order. The second number specifies the number band of the memory involved if meaningful; thus, the instruction \neq does not involve the memory, but \neq does. The third number specifies the memory band of the next instruction. For example, in sector 06, band 1, the instruction $\text{md}_1 \ 2,4,1$ 3T occurs. This means that the number in number band 4 should be transferred to the D register, sector 1, after a 2 word wait, and that the next instruction, \neq 4T, will be found immediately after execution in band 1. The instruction was then read out during sector (word) #06, the computer did nothing during sectors #07 and #08, transferred the number found in number band 4, sector #09, to the D register during sector #09, and read instruction \neq 4T during sector #10. Note that the D register is eight words long, and arbitrarily sector 1 of the D register coincides with sector 1 of the sixty four word memory. Thus the D register repeats itself starting with sectors 9, 17, etc. of the memory.

The permissible words to wait before execution contained in any instruction can be anything from 0 to 16 words, except the wait instruction (wt) which can have 0 to 32 words wait. The wait instruction is executed immediately, or rather it would be better to say that execution corresponds to reading the next instruction. For example,

check instruction #159F in sector 52, band 2, which feeds into instruction #1F.

Note that a particular operation to be performed by an instruction may be wrong. As long as the address of the next instruction is correct the computer will continue to cycle instructions blindly. This is of particular importance in trouble shooting. The usual procedure is to make the instructions cycle, then worry about what mathematical results are obtained.

The three programs all start in sector #1, but in different memory bands. The starting position is selected either by a set of buttons on the computer, or by the last instruction read by the computer. Thus, when instruction #148F is read and the computer stops ready to start on the entry program, the address of the next instruction is band 3. When the computer is started again by pushbutton, the instruction #1E will be read first.

It is by means of the variable words to wait portion of an instruction that sixteen different fix positions are entered and taken out of the memory. However, in the actual number representing a particular instruction, the compliment of the words to wait appears. Thus, the four digits representing the words to wait will appear oddly when added to in the manner shown. When all four digits are zero, this means 16 words to wait; adding one least significant digit means 8

words to wait, etc. See number band 2.

Rather than taking up the detailed coding step by step, the interested reader may follow through as much of Table I as necessary to get the system in mind. Compare Tables I, III and IV with emphasis on the operation of the conditional transfer instruction **ckS** and the variable words to wait.

It must be obvious to anyone who has followed the coding in any detail that there is much wasted time and space here. The problem has become not one of electronics or control system design, but rather one for an ingenious bookkeeper and for numerical analysis. Time did not permit completion. If this control system were to be used in an important application, however, such effort would be essential to a good design.

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CHAPTER IV. GENERAL DISCUSSION AND RECOMMENDATIONS

The test program used in this device was a good one in that all functions of the computer were tested. However, diagnostic indication of troubles encountered was very limited. A test should give a positive indication to a serviceman of the location of troubles. The instructions available in even as unsophisticated a computer as the Model I should allow this by making more liberal use of the ck0 instruction throughout the test program shown in Table I. Since a digital computer is so literal and human coding so liable to error, one must know whether the machine is at fault or not before spending the hours required to trouble shoot a program for a control system.

Once assured of proper machine operation, several steps can be taken to get a program to cycle instructions correctly. As noted previously, it is usual to cycle instructions, then run test problems to check mathematical operations. After entering a set of instructions into the computer in which a mistake is made, improper cycling will usually result in circulation through an improper sequence of instructions. If this occurs, the following steps are of value with the Model I computer.

1. Change an instruction, say about half way through the program, to a ck0 at some point where the computer will surely stop. If this half of the instructions cycles correctly and gives proper intermediate results from a test problem, put the instruction back and change another instruction say three quarters of the way through. Continue this pro-

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cedure till the trouble is narrowed down.

2. After narrowing down, change one or more instructions to cycle only a small portion of the program repeatedly, and get it to work. This might be called reentrant checking.

3. Another method after narrowing down is to use test equipment built into computer (provided in most computers) which will allow execution of a single instruction at a time. Check each step in a suspected region.

4. In troublesome cases it may be necessary to check each instruction with an oscilloscope. As might be suspected, this is time consuming and should be avoided if possible.

5. A good deal of ingenuity helps more than set rules.

When proper cycling is accomplished some previously prepared test problems should be used to check operations. The method used with this set of programs was to disconnect the input equipment, write in known numbers where the input numbers would have been written, and check either the final output, or the numbers held in the registers at some intermediate time, using the narrowing down technique previously described.

If now the computations are properly made by the computer, the rest of the control system comes under scrutiny, especially the stability of the system and errors. Note that the program in use is an integral part of the control system, and must be thought of as part of the equipment.

A useful concept in present control systems is the transfer function

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either of the system or its components. A program may be thought of in terms of a transfer function involving principally functions of the term $\exp(-as)$, a time lag (9). Unfortunately, too little has been done to develop a theory for this concept. It is mostly a study of numerical analysis (9).

Damping of a control system has an analog in a digital computer program. Derivatives and integrals are replaced in these discrete calculations with differences and sums. Damping then becomes smoothing, which may take the form of averaging or interpolation, or approximation of the required derivatives by differences. The problem is one of numerical analysis and will be discussed further only in connection with noise.

A simple method of estimating stability was suggested by Dr. Jacobi for the control system described. Since it is a feedback system involving positive feedback, oscillation could occur when the total phase shift became a multiple of 2π . The fly program has a time delay of 0.1 second, or a phase shift of $\phi_1 = W/10$, where w is the angular frequency. The RC filter used on the output equipment has a phase shift $\phi_2 = wRC$, where $RC = 0.5$. Oscillation at $w = 0$ is meaningless. $\phi = \phi_1 + \phi_2 = 2\pi$ occurs when $w = 15 \pi$, or at a frequency of 7.5 cps. However, the RC filter has an attenuation of 27 db. at this frequency so no trouble was expected or encountered. When the filter was disconnected for trial, oscillation, or at least random action did occur although the pen would of course not follow the gyrations of the numbers in the computer. Note that the same

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34/34/34

smoothing effect could have been attained within the program had it been designed into the program.

Errors within the computations (excluding a steady bias error) may arise from two principal sources. Round-off errors appear as white noise. Large random errors may occur due to electrical interference or errors in programming (see pg. 12), or due to marginally satisfactory equipment within the computer. The random errors may be reduced by proper design and maintenance, but probably cannot be eliminated. Both types of noise can be reduced within the program by smoothing. White noise is most effectively reduced by some means of averaging or interpolation. Large random errors can be treated, like ignition noise, by limiting the value of successive increments in an iterative process, e.g., limiting dx and dy in the fly problem.

An error which occurs as a bias error, e.g., a wrong scale factor, can cause considerable trouble in a system involving feedback. Scale factor is contained in the input and output equipments, within the program, and in any analog components external to these, particularly the sensors. Thus the accuracy of the overall system is still determined by the weakest link. To take advantage of the possible accuracy of most digital computers, then, attention should be directed to the design of the analog components of the system, as well as to the program. In a time-sharing system it would be of value to utilize one computing

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1. *Introduction*

1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100. 101. 102. 103. 104. 105. 106. 107. 108. 109. 110. 111. 112. 113. 114. 115. 116. 117. 118. 119. 120. 121. 122. 123. 124. 125. 126. 127. 128. 129. 130. 131. 132. 133. 134. 135. 136. 137. 138. 139. 140. 141. 142. 143. 144. 145. 146. 147. 148. 149. 150. 151. 152. 153. 154. 155. 156. 157. 158. 159. 160. 161. 162. 163. 164. 165. 166. 167. 168. 169. 170. 171. 172. 173. 174. 175. 176. 177. 178. 179. 180. 181. 182. 183. 184. 185. 186. 187. 188. 189. 190. 191. 192. 193. 194. 195. 196. 197. 198. 199. 200. 201. 202. 203. 204. 205. 206. 207. 208. 209. 210. 211. 212. 213. 214. 215. 216. 217. 218. 219. 220. 221. 222. 223. 224. 225. 226. 227. 228. 229. 230. 231. 232. 233. 234. 235. 236. 237. 238. 239. 240. 241. 242. 243. 244. 245. 246. 247. 248. 249. 250. 251. 252. 253. 254. 255. 256. 257. 258. 259. 260. 261. 262. 263. 264. 265. 266. 267. 268. 269. 270. 271. 272. 273. 274. 275. 276. 277. 278. 279. 280. 281. 282. 283. 284. 285. 286. 287. 288. 289. 290. 291. 292. 293. 294. 295. 296. 297. 298. 299. 300. 301. 302. 303. 304. 305. 306. 307. 308. 309. 310. 311. 312. 313. 314. 315. 316. 317. 318. 319. 320. 321. 322. 323. 324. 325. 326. 327. 328. 329. 330. 331. 332. 333. 334. 335. 336. 337. 338. 339. 340. 341. 342. 343. 344. 345. 346. 347. 348. 349. 350. 351. 352. 353. 354. 355. 356. 357. 358. 359. 360. 361. 362. 363. 364. 365. 366. 367. 368. 369. 370. 371. 372. 373. 374. 375. 376. 377. 378. 379. 380. 381. 382. 383. 384. 385. 386. 387. 388. 389. 390. 391. 392. 393. 394. 395. 396. 397. 398. 399. 400. 401. 402. 403. 404. 405. 406. 407. 408. 409. 410. 411. 412. 413. 414. 415. 416. 417. 418. 419. 420. 421. 422. 423. 424. 425. 426. 427. 428. 429. 430. 431. 432. 433. 434. 435. 436. 437. 438. 439. 440. 441. 442. 443. 444. 445. 446. 447. 448. 449. 450. 451. 452. 453. 454. 455. 456. 457. 458. 459. 460. 461. 462. 463. 464. 465. 466. 467. 468. 469. 470. 471. 472. 473. 474. 475. 476. 477. 478. 479. 480. 481. 482. 483. 484. 485. 486. 487. 488. 489. 490. 491. 492. 493. 494. 495. 496. 497. 498. 499. 500. 501. 502. 503. 504. 505. 506. 507. 508. 509. 510. 511. 512. 513. 514. 515. 516. 517. 518. 519. 520. 521. 522. 523. 524. 525. 526. 527. 528. 529. 530. 531. 532. 533. 534. 535. 536. 537. 538. 539. 540. 541. 542. 543. 544. 545. 546. 547. 548. 549. 550. 551. 552. 553. 554. 555. 556. 557. 558. 559. 560. 561. 562. 563. 564. 565. 566. 567. 568. 569. 570. 571. 572. 573. 574. 575. 576. 577. 578. 579. 580. 581. 582. 583. 584. 585. 586. 587. 588. 589. 590. 591. 592. 593. 594. 595. 596. 597. 598. 599. 600. 601. 602. 603. 604. 605. 606. 607. 608. 609. 610. 611. 612. 613. 614. 615. 616. 617. 618. 619. 620. 621. 622. 623. 624. 625. 626. 627. 628. 629. 630. 631. 632. 633. 634. 635. 636. 637. 638. 639. 640. 641. 642. 643. 644. 645. 646. 647. 648. 649. 650. 651. 652. 653. 654. 655. 656. 657. 658. 659. 660. 661. 662. 663. 664. 665. 666. 667. 668. 669. 670. 671. 672. 673. 674. 675. 676. 677. 678. 679. 680. 681. 682. 683. 684. 685. 686. 687. 688. 689. 690. 691. 692. 693. 694. 695. 696. 697. 698. 699. 700. 701. 702. 703. 704. 705. 706. 707. 708. 709. 710. 711. 712. 713. 714. 715. 716. 717. 718. 719. 720. 721. 722. 723. 724. 725. 726. 727. 728. 729. 730. 731. 732. 733. 734. 735. 736. 737. 738. 739. 740. 741. 742. 743. 744. 745. 746. 747. 748. 749. 750. 751. 752. 753. 754. 755. 756. 757. 758. 759. 760. 761. 762. 763. 764. 765. 766. 767. 768. 769. 770. 771. 772. 773. 774. 775. 776. 777. 778. 779. 780. 781. 782. 783. 784. 785. 786. 787. 788. 789. 790. 791. 792. 793. 794. 795. 796. 797. 798. 799. 800. 801. 802. 803. 804. 805. 806. 807. 808. 809. 810. 811. 812. 813. 814. 815. 816. 817. 818. 819. 820. 821. 822. 823. 824. 825. 826. 827. 828. 829. 830. 831. 832. 833. 834. 835. 836. 837. 838. 839. 840. 84

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cycle for recomputing and writing a new scale factor into the program periodically, i.e., automatic calibration.

Using a digital machine implies both quantizing and sampling; these should be consistent with system design. When high sampling rates are required, e.g., high roll rates of present jet aircraft, a stringent limitation is placed on the program designer and the computer engineer to make an efficient (few words per cycle) and rapid (many words per second) machine. Low quantizing error may be required in some applications. These two conditions are unfortunately contradictory in a serial machine. This is especially unfortunate when one equipment is used on a time-sharing basis for many jobs. The use of a parallel machine may be required with its higher speed of operation but greater amount of equipment, if the program designer is not dexterous enough.

A program may be made more efficient by efforts of the numerical analyst in reducing the steps required to do the series of operations. The coding of a particular program is a related but different problem. In coding, each wait for the appearance of a number in the memory is inefficient, as are completely filled sectors when other sectors are relatively vacant (compare sectors 5 and 55 of Table I). The requirements of coding will probably determine the details of the computer design in the long run. Efficient coding is the result of attention paid to a great many small details.

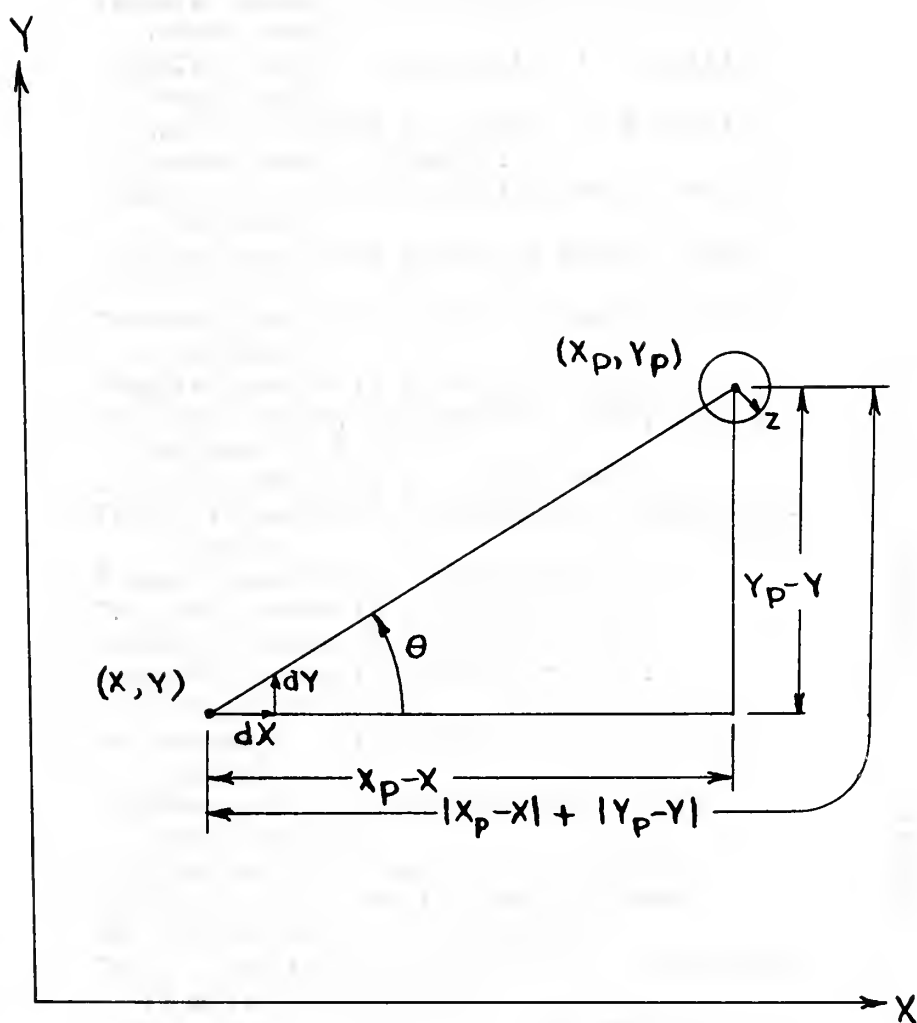


FIGURE 11. GEOMETRY OF FLY PROBLEM.

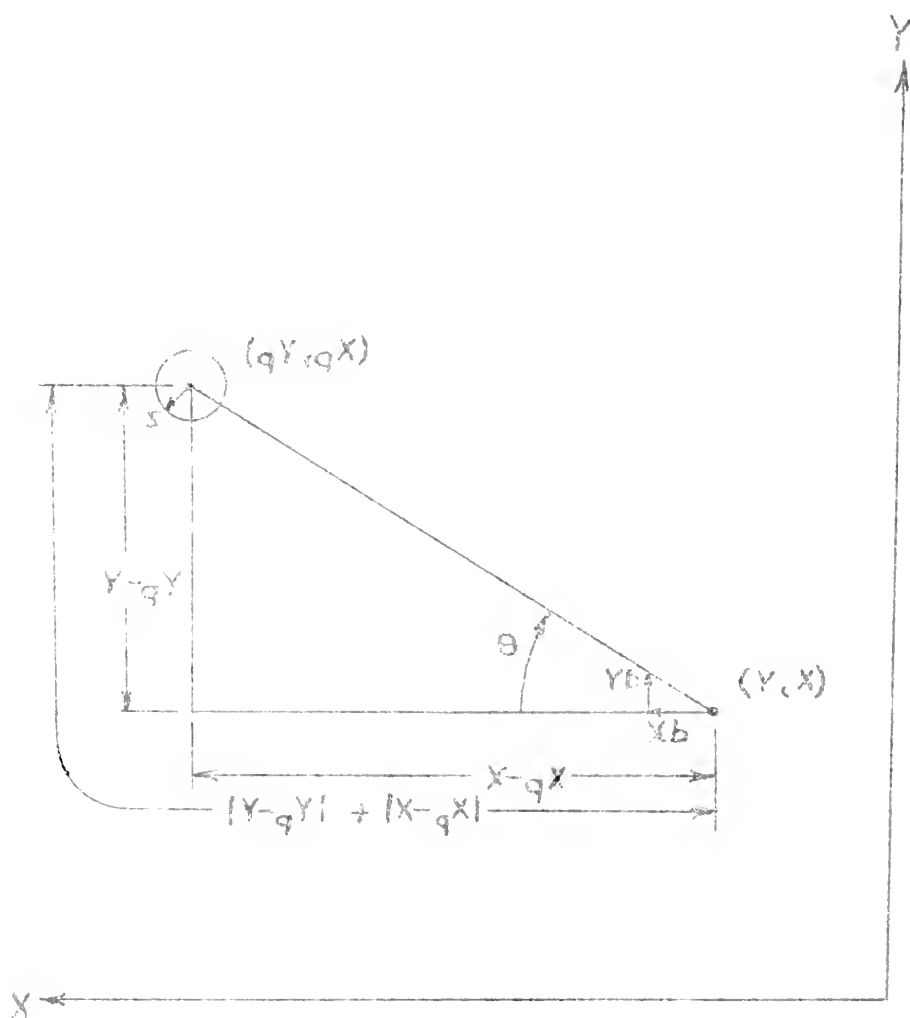


FIGURE II. GEOMETRY OF FLY PROBLEM.

| <u>Symbol</u> | <u>Meaning</u> | <u>Words to
Execute</u> |
|---------------|---|-----------------------------|
| cm | Transfer number in c register to specified
memory band | 1 |
| am | Transfer number in a register to specified
number band | 1 |
| dm. | Transfer number in d register to specified
number band | 1 |
| bm | Transfer number in b register to specified
number band. b cleared. | 1 |
| ma | Transfer number in specified number band to
a register | 1 |
| mc | Transfer number in specified number band to
c register | 1 |
| md | Transfer number in specified number band to
d register | 1 |
| ca | Transfer number in c register to a | 1 |
| Aca | Transfer number, disregarding sign, from c
register to a | 1 |
| da | Transfer number in d register to a | 1 |
| ba | Transfer number in b register to a register.
b cleared | 1 |
| cd | Transfer number in c register to d. | 1 |
| ad | Transfer number in a register to d. | 1 |
| dc | Transfer number in d register to c. | 1 |
| bd | Transfer number in b register to d.
b register cleared | 1 |
| + | Add number in a to number in b, sum in b
register | 1 |
| - | Subtract number in a from number in b,
difference in b | 1 |
| X | Multiply a by c, result in b register | 16 |
| div | Divide b by a, result in c, b cleared | 16 |
| wt | Do nothing for (1 to 32) words | 0 |
| ck0 | Check b register. If zero go to next order.
If not, stop computer | 1 |
| ckS | Check sign of number in a. If positive - -
If negative - - | 1
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Table II. Instructions available in Model I
Digital Computer.

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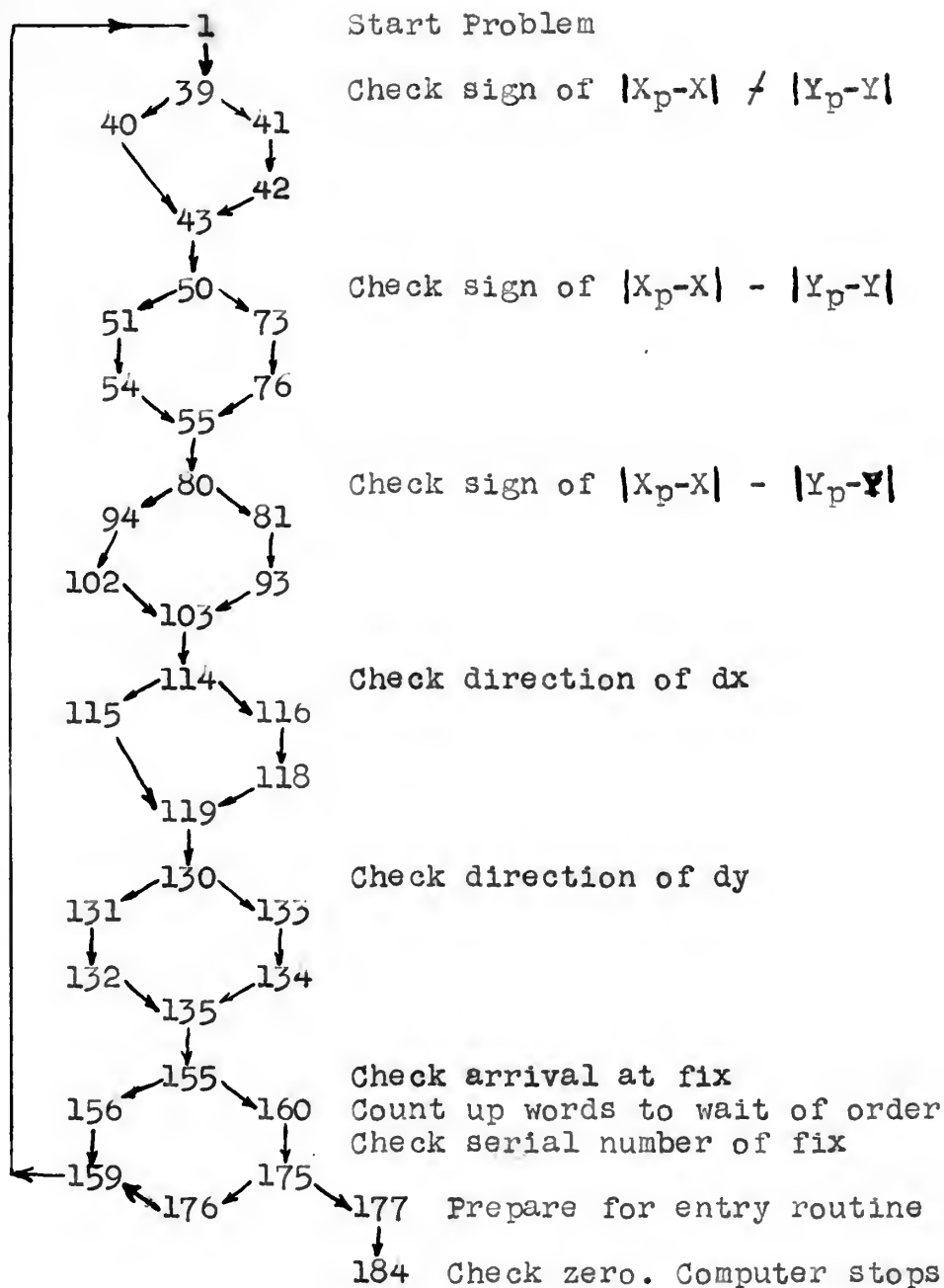


Table III. Flow Diagram of Fly Instructions

Table III. Flow Diagram of Fly Instructions

| | | |
|-----------------------------------|-----|-----|
| 184 Check zero. Computer stops | 176 | 159 |
| 177 Prepare for entry routine | 175 | 158 |
| Check serial number of fix | 160 | 156 |
| Count up words to wait of order | 155 | 155 |
| Check arrival at fix | 135 | 132 |
| | 134 | 131 |
| Check direction of dy | 133 | 130 |
| | 119 | 115 |
| | 118 | 114 |
| Check direction of dx | 116 | 103 |
| | 97 | 102 |
| Check sign of $X_p - X - Y_p - Y$ | 81 | 94 |
| | 80 | 76 |
| | 55 | 54 |
| | 76 | 51 |
| Check sign of $X_p - X - Y_p - Y$ | 73 | 50 |
| | 43 | 40 |
| | 42 | 39 |
| Check sign of $X_p - X - Y_p - Y$ | 41 | 38 |
| Start Problem | 1 | |

| <u>Inst.</u> | <u>No. in A Reg.</u> | <u>No. in B Reg.</u> | <u>No. in C Reg.</u> | <u>No. in memory</u> |
|--------------|----------------------|----------------------|----------------------|----------------------|
| 1.ba | | 0 | | |
| 2.ma | X_p | | | |
| 3.mc | | | Y_p | |
| 4.cd8 | | | | Y_p in D_8 |
| 5.ad3 | | | | X_p in D_3 |
| 6.wt | | | | |
| 7.md6 | | | | X_{u1} in D_6 |
| 8.ma | X_{u1} | | | |
| 9./ | | Y_u | | |
| 10.ma | S.C. | | | |
| 11.div | | 0 | Y | |
| 12.cd7 | | | | Y in D_7 |
| 13.d6a | X_u | | | |
| 14./ | | X_{u1} | | |
| 15.ma | S.C. | | | |
| 16.div | | 0 | X | |
| 17.cd6 | | | | X in D_6 |
| 18.d3a | X_p | | | |
| 19./ | | X_p | | |
| 20.d6a | X | | | |
| 21.- | | $X_p - X = K$ | | |
| 22.bd2 | | 0 | | K in D_2 |
| 23.d2c | | | K | |
| 24.Aca | $K' = K $ | | | |
| 25.ad1 | | | | K' in D_1 |

Table IV. Program of Fly Instructions.

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| <u>Inst.</u> | <u>No. in A Reg.</u> | <u>No. in B Reg.</u> | <u>No. in C Reg.</u> | <u>No. in Memory</u> |
|--------------|----------------------------------|----------------------|----------------------|-------------------------|
| 26.dga | Y_p | | | |
| 27.f | | Y_p | | |
| 28.dga | Y | | | |
| 29.- | | $Y_p - Y = L$ | | |
| 30.bd4 | | 0 | | L in D_1 |
| 31.d4c | | | L | |
| 32.Aca | $L' = L $ | | | |
| 33.ad5 | | | | L' in D_5 |
| 34.d1a | K' | | | |
| 35. f | | K' | | |
| 36.d5a | L' | | | |
| 37.f | | K' / L' | | |
| 38.ba | K' / L' | 0 | | |
| 39.ckS | If \neq , to 40
If -, to 41 | | | |
| 40.wt | | | | |
| 41.ma | $\frac{1}{4}$ | | | |
| 42.wt | | | | |
| 43.am | | | | K' / L' or 4
in n. |
| 44.d1a | K' | | | |
| 45.f | | K' | | |
| 46.d5a | L' | | | |
| 47.- | | $K' - L'$ | | |
| 48.ba | $K' - L'$ | 0 | | |
| 49.am | | | | $K' - L'$ in m. |
| 50.ckS | If \neq , to 51
If -, to 73 | | | |

| <u>Inst.</u> | <u>No. in A Reg.</u> | <u>No. in B Reg.</u> | <u>No. in C Reg.</u> | <u>No. in memory</u> |
|--------------------|----------------------------|----------------------|--------------------------|-------------------------------------|
| 51.Aca | L' | | | |
| 52.f | | L' | | |
| 53.d _{2a} | K | | | |
| 54.div | | 0 | $L'/K = \pm \tan \theta$ | |
| 55.ca | $\tan \theta, \cot \theta$ | | | |
| 56.ad ₁ | | | | \tan in D ₁ |
| 57.X | | \tan^2 | | |
| 58.ba | \tan^2 | 0 | | |
| 59.ad ₂ | | | | \tan^2 in D ₂ |
| 60.d _{2c} | | | \tan^2 | |
| 61.X | | \tan^4 | | |
| 62.bd ₅ | | 0 | | \tan^4 in D ₅ |
| 63.ma | -0.4340 | | | |
| 64.X | | $-.434 \tan^2$ | | |
| 65.bd ₄ | | 0 | | $-.434 \tan^2$
in D ₄ |
| 66.d _{5c} | | | \tan^4 | |
| 67.ma | 0.1474 | | | |
| 68.X | | $.1474 \tan^4$ | | |
| 69.d _{4a} | $-.434 \tan^2$ | | | |
| 70.f | | sum | | |
| 71.ma | 0.9965 | | | |
| 72.f | next inst 77 | $\cos \theta$ | | |
| 73.d _{1a} | K' | | | |
| 74.f | | K' | | |
| 75.Aca | L' | | | |

Table IV. Continued

| <u>Inst.</u> | <u>No. in A Reg.</u> | <u>No. in B Reg.</u> | <u>No. in C. Reg.</u> | <u>No. in memory</u> |
|--------------|-------------------------------------|----------------------|-----------------------|-------------------------|
| 76.div | Next inst 55 | 0 | $K'/L' = \cot \theta$ | |
| 77.bd4 | | 0 | | cos or cos/cot
in D4 |
| 78.wt | | | | |
| 79.ma | $K'-L'$ | | | |
| 80.clS | if \neq , to 94
if $=$, to 81 | | | |
| 81.d4c | | | cos/cot | |
| 82.d1a | cot | | | |
| 83.X | | cos θ | | |
| 84.bd4 | | 0 | | cos in D4 |
| 85.mc | | | Vdt | |
| 86.d4a | cos θ | | | |
| 87.X | | dx | | |
| 88.ba | dx | 0 | | |
| 89.ad2 | | | | dx in D2 |
| 90. \neq | | dx | | |
| 91.d1a | cot θ | | | |
| 92.div | | 0 | dy | |
| 93.cd5 | next ins 103 | | | dy in d5. |
| 94.mc | | | Vdt | |
| 95.d4a | cos θ | | | |
| 96.X | | dx | | |
| 97.ba | dx | 0 | | |
| 98.ad2 | | | | dx in D2 |
| 99.d1c | | | tan θ | |
| 100.X | | dy | | |

Table IV. Continued

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| 75 | 100.00 |
| 76 | 100.00 |
| 77 | 100.00 |
| 78 | 100.00 |
| 79 | 100.00 |
| 80 | 100.00 |
| 81 | 100.00 |
| 82 | 100.00 |
| 83 | 100.00 |
| 84 | 100.00 |
| 85 | 100.00 |
| 86 | 100.00 |
| 87 | 100.00 |
| 88 | 100.00 |
| 89 | 100.00 |
| 90 | 100.00 |
| 91 | 100.00 |
| 92 | 100.00 |
| 93 | 100.00 |
| 94 | 100.00 |
| 95 | 100.00 |
| 96 | 100.00 |
| 97 | 100.00 |
| 98 | 100.00 |
| 99 | 100.00 |
| 100 | 100.00 |

| <u>Inst.</u> | <u>No.in A Reg.</u> | <u>No.in B Reg.</u> | <u>No.in C Reg.</u> | <u>No.in memory</u> |
|--------------|------------------------------|---------------------|---------------------|------------------------|
| 101.bd5 | | 0 | | dy in D ₅ |
| 102.wt | | | | |
| 103.d3a | X _p | | | |
| 104./ | | X _p | | |
| 105.d6a | X | | | |
| 106.- | | X _p -X=K | | |
| 107.bd4 | | 0 | | K in D ₄ |
| 108.d2a | dx | | | |
| 109./ | | dx | | |
| 110.d4a | K | | | |
| 111.div | | 0 | dx/K | |
| 112.cd1 | | | | dx/K in D ₁ |
| 113.d1a | dx/K | | | |
| 114.cKS | if /, to 115
if -, to 116 | | | |
| 115.wt | next ins 119 | | | |
| 116.d2a | dx | | | |
| 117.- | | -dx=dx* | | |
| 118.bd2 | | 0 | | dx* in D ₂ |
| 119.d6a | Y _p | | | |
| 120./ | | Y _p | | |
| 121.d7a | Y | | | |
| 122.- | | Y _p -Y=L | | |
| 123.bd4 | | 0 | | L in D ₄ |
| 124.d5a | dy | | | |
| 125./ | | dy | | |

Table IV. Continued

1

| <u>Inst.</u> | <u>No. in A Reg.</u> | <u>No. in B Reg.</u> | <u>No. in C Reg.</u> | <u>No. in Memory</u> |
|--------------|---------------------------------------|-----------------------------|----------------------|------------------------|
| 126.d4a | L | | | |
| 127.div | | 0 | dy/L | |
| 128.cd1 | | | | dy/L in L1 |
| 129.d1a | dy/L | | | |
| 130.ckS | if \neq , to 131
if $=$, to 133 | | | |
| 131.d5a | dy | | | |
| 132. \neq | next ins135 | dy | | |
| 133.d5a | dy | | | |
| 134.- | | $-dy = dy^*$ | | |
| 135.ba | dy^* | 0 | | |
| 136.ad5 | | | | dy^* in D5 |
| 137. \neq | | dy^* | | |
| 138.d7a | Y | | | |
| 139. \neq | | $Y \neq dy^* = Y_n \neq 1.$ | | |
| 140.bd5 | | 0 | | $Y_n \neq 1$ in D5 |
| 141.d2a | dx^* | | | |
| 142. \neq | | dx^* | | |
| 143.d6a | X | | | |
| 144. \neq | | $X \neq dx^* = X_n \neq 1$ | | |
| 145.ba | $X_n \neq 1$ | 0 | | |
| 146.d5c | | | $Y_n \neq 1$ | |
| 147.am | | | | $X_n \neq 1$ in output |
| 148.ad1 | | | | $X_n \neq 1$ in D1 |
| 149.cm | | | | $Y_n \neq 1$ in output |
| 150.ma | $K' \neq L'$ or $\frac{1}{4}$ | | | |

Table IV. Continued

| <u>Inst.</u> | <u>No. in A Reg.</u> | <u>No. in B Reg.</u> | <u>No. in C Reg.</u> | <u>No. in memory</u> |
|----------------------|------------------------------------|------------------------------|-----------------------|----------------------------------|
| 151. \neq | | $K'\neq L'$ or $\frac{1}{4}$ | | |
| 152.ma | z | | | |
| 153.- | | $(K'\neq L')-z$ | | |
| 154.ba | $(K'\neq L')-z$ | 0 | | |
| 155.ckS | if \neq , to 156
if -, to 160 | | | |
| 156.wt | | | | |
| 157.wt | | | | |
| 158.wt | | | | |
| 159.wt | next inst 1 | | | |
| 160.wt | | | | |
| 161.ma | old ma
instruction | | | |
| 162. \neq | | old ma
instruction | | |
| 163.ma | 1/16 | | | |
| 164. \neq | | new ma
instruction | | |
| 165.bd ₄ | | 0 | | new ma inst
in D ₄ |
| 166.ma | $2^{-4}\neq 2^{-14}$ | | | |
| 167. \neq | | $2^{-4}\neq 2^{-14}$ | | |
| 168.ma | count no. | | | |
| 169. \neq | | new count no. | | |
| 170.ba | new count no | 0 | | |
| 171.wt | | | | |
| 172.d ₄ c | | | new ma
instruction | |
| 173.cm | | | | new ma inst
in memory. |
| 174.am | | | | new count no.
in memory. |
| 175.ckS | if \neq , to 176
if -, to 177 | | | |

Table IV. Continued

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1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022, 2023, 2024, 2025, 2026, 2027, 2028, 2029, 2030, 2031, 2032, 2033, 2034, 2035, 2036, 2037, 2038, 2039, 2040, 2041, 2042, 2043, 2044, 2045, 2046, 2047, 2048, 2049, 2050, 2051, 2052, 2053, 2054, 2055, 2056, 2057, 2058, 2059, 2060, 2061, 2062, 2063, 2064, 2065, 2066, 2067, 2068, 2069, 2070, 2071, 2072, 2073, 2074, 2075, 2076, 2077, 2078, 2079, 2080, 2081, 2082, 2083, 2084, 2085, 2086, 2087, 2088, 2089, 2090, 2091, 2092, 2093, 2094, 2095, 2096, 2097, 2098, 2099, 2100, 2101, 2102, 2103, 2104, 2105, 2106, 2107, 2108, 2109, 2110, 2111, 2112, 2113, 2114, 2115, 2116, 2117, 2118, 2119, 2120, 2121, 2122, 2123, 2124, 2125, 2126, 2127, 2128, 2129, 2130, 2131, 2132, 2133, 2134, 2135, 2136, 2137, 2138, 2139, 2140, 2141, 2142, 2143, 2144, 2145, 2146, 2147, 2148, 2149, 2150, 2151, 2152, 2153, 2154, 2155, 2156, 2157, 2158, 2159, 2160, 2161, 2162, 2163, 2164, 2165, 2166, 2167, 2168, 2169, 2170, 2171, 2172, 2173, 2174, 2175, 2176, 2177, 2178, 2179, 2180, 2181, 2182, 2183, 2184, 2185, 2186, 2187, 2188, 2189, 2190, 2191, 2192, 2193, 2194, 2195, 2196, 2197, 2198, 2199, 2200, 2201, 2202, 2203, 2204, 2205, 2206, 2207, 2208, 2209, 2210, 2211, 2212, 2213, 2214, 2215, 2216, 2217, 2218, 2219, 2220, 2221, 2222, 2223, 2224, 2225, 2226, 2227, 2228, 2229, 2230, 2231, 2232, 2233, 2234, 2235, 2236, 2237, 2238, 2239, 2240, 2241, 2242, 2243, 2244, 2245, 2246, 2247, 2248, 2249, 2250, 2251, 2252, 2253, 2254, 2255, 2256, 2257, 2258, 2259, 2260, 2261, 2262, 2263, 2264, 2265, 2266, 2267, 2268, 2269, 2270, 2271, 2272, 2273, 2274, 2275, 2276, 2277, 2278, 2279, 2280, 2281, 2282, 2283, 2284, 2285, 2286, 2287, 2288, 2289, 2290, 2291, 2292, 2293, 2294, 2295, 2296, 2297, 2298, 2299, 2300, 2301, 2302, 2303, 2304, 2305, 2306, 2307, 2308, 2309, 2310, 2311, 2312, 2313, 2314, 2315, 2316, 2317, 2318, 2319, 2320, 2321, 2322, 2323, 2324, 2325, 2326, 2327, 2328, 2329, 2330, 2331, 2332, 2333, 2334, 2335, 2336, 2337, 2338, 2339, 2340, 2341, 2342, 2343, 2344, 2345, 2346, 2347, 2348, 2349, 2350, 2351, 2352, 2353, 2354, 2355, 2356, 2357, 2358, 2359, 2360, 2361, 2362, 2363, 2364, 2365, 2366, 2367, 2368, 2369, 2370, 2371, 2372, 2373, 2374, 2375, 2376, 2377, 2378, 2379, 2380, 2381, 2382, 2383, 2384, 2385, 2386, 2387, 2388, 2389, 2390, 2391, 2392, 2393, 2394, 2395, 2396, 2397, 2398, 2399, 2400, 2401, 2402, 2403, 2404, 2405, 2406, 2407, 2408, 2409, 2410, 2411, 2412, 2413, 2414, 2415, 2416, 2417, 2418, 2419, 2420, 2421, 2422, 2423, 2424, 2425, 2426, 2427, 2428, 2429, 2430, 2431, 2432, 2433, 2434, 2435, 2436, 2437, 2438, 2439, 2440, 2441, 2442, 2443, 2444, 2445, 2446, 2447, 2448, 2449, 2450, 2451, 2452, 2453, 2454, 2455, 2456, 2457, 2458, 2459, 2460, 2461, 2462, 2463, 2464, 2465, 2466, 2467, 2468, 2469, 2470, 2471, 2472, 2473, 2474, 2475, 2476, 2477, 2478, 2479, 2480, 2481, 2482, 2483, 2484, 2485, 2486, 2487, 2488, 2489, 2490, 2491, 2492, 2493, 2494, 2495, 2496, 2497, 2498, 2499, 2500, 2501, 2502, 2503, 2504, 2505, 2506, 2507, 2508, 2509, 2510, 2511, 2512, 2513, 2514, 2515, 2516, 2517, 2518, 2519, 2520, 2521, 2522, 2523, 2524, 2525, 2526, 2527, 2528, 2529, 2530, 2531, 2532, 2533, 2534, 2535, 2536, 2537, 2538, 2539, 2540, 2541, 2542, 2543, 2544, 2545, 2546, 2547, 2548, 2549, 2550, 2551, 2552, 2553, 2554, 2555, 2556, 2557, 2558, 2559, 2560, 2561, 2562, 2563, 2564, 2565, 2566, 2567, 2568, 2569, 2570, 2571, 2572, 2573, 2574, 2575, 2576, 2577, 2578, 2579, 2580, 2581, 2582, 2583, 2584, 2585, 2586, 2587, 2588, 2589, 2590, 2591, 2592, 2593, 2594, 2595, 2596, 2597, 2598, 2599, 2600, 2601, 2602, 2603, 2604, 2605, 2606, 2607, 2608, 2609, 2610, 2611, 2612, 2613, 2614, 2615, 2616, 2617, 2618, 2619, 2620, 2621, 2622, 2623, 2624, 2625, 2626, 2627, 2628, 2629, 2630, 2631, 2632, 2633, 2634, 2635, 2636, 2637, 2638, 2639, 2640, 2641, 2642, 2643, 2644, 2645, 2646, 2647, 2648, 2649, 2650, 2651, 2652, 2653, 2654, 2655, 2656, 2657, 2658, 2659, 2660, 2661, 2662, 2663, 2664, 2665, 2666, 2667, 2668, 2669, 2670, 2671, 2672, 2673, 2674, 2675, 2676, 2677, 2678, 2679, 26

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4. 2. 2.

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- 1 -

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1. 2. 3.

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| <u>Inst.</u> | <u>No.in A Reg.</u> | <u>No.in B Reg.</u> | <u>No.in C Reg.</u> | <u>No.in memory</u> |
|--------------|---------------------------|---------------------|---------------------|--------------------------|
| 176.wt | next insl59
(recycles) | | | |
| 177.ma | 0 | | | |
| 178.wt | | | | |
| 179.am | | | | 0 in output 4 |
| 180.ma | new am inst | | | |
| 181.wt | | | | |
| 182.am | | | | new am inst
in memory |
| 183./ | | new am inst | | |
| 184.clk0 | stop computer | | | |

Table IV. Continued

| <u>Inst.</u> | <u>No.in A Reg.</u> | <u>No.in B Reg.</u> | <u>No.in C Reg.</u> | <u>No.in memory</u> |
|---------------------|-----------------------|-----------------------|---------------------|----------------------------------|
| 1.ba | | 0 | | |
| 2.ma | old am
instruction | | | |
| 3.f | | old am
instruction | | |
| 4.ma | 1/16 | | | |
| 5.f | | new am
instruction | | |
| 6.bd ₄ | | 0 | | new am inst
in D ₄ |
| 7.ma | X _u | | | |
| 8.md ₈ | | | | Y _u in D ₈ |
| 9.f | | X _u | | |
| 10.ma | S.C. | | | |
| 11.div | | 0 | X | |
| 12.dga | Y _u | | | |
| 13.cd ₂ | | | | X in D ₂ |
| 14.f | | Y _u | | |
| 15.ma | S.C. | | | |
| 16.div | | 0 | Y | |
| 17.d ₂ a | X | | | |
| 18.d ₄ m | | | | new am inst
in memory |
| 19.wt | | | | |
| 20.wt | | | | |

Table V. Program of Entry Instructions.

1. 2. 3. 4. 5. 6. 7. 8. 9. 10.

1. 2. 3. 4. 5. 6. 7. 8. 9. 10.

| <u>Inst.</u> | <u>No.in A Reg.</u> | <u>No.in B Reg.</u> | <u>No.in C Reg.</u> | <u>No.in memory</u> |
|--------------|---------------------|---------------------|---------------------|---------------------------|
| 21.am | | | | X in memory |
| 22.cm | | | | Y in memory |
| 23.mc | | | 0 | |
| 24.ma | $\frac{1}{2}$ | | | |
| 25.f | | $\frac{1}{2}$ | | |
| 26.cm | | | | 0 in output 4 |
| 27.clk0 | Computer
stops | | | |
| 28.mc | | | ma instr | |
| 29.ma | $1-2^{-7}$ | | | |
| 30.f | | $1-2^{-7}$ | | |
| 31.cm | | | | ma inst in
memory |
| 32.mc | | | 0 | |
| 33.am | | | | full scale in
output 4 |
| 34.cm | | | | 0 in count no. |
| 35.clk0 | Computer
stops | | | |

Table V. Continued

1. 2. 3. 4. 5. 6. 7. 8. 9. 10.

11.

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15.

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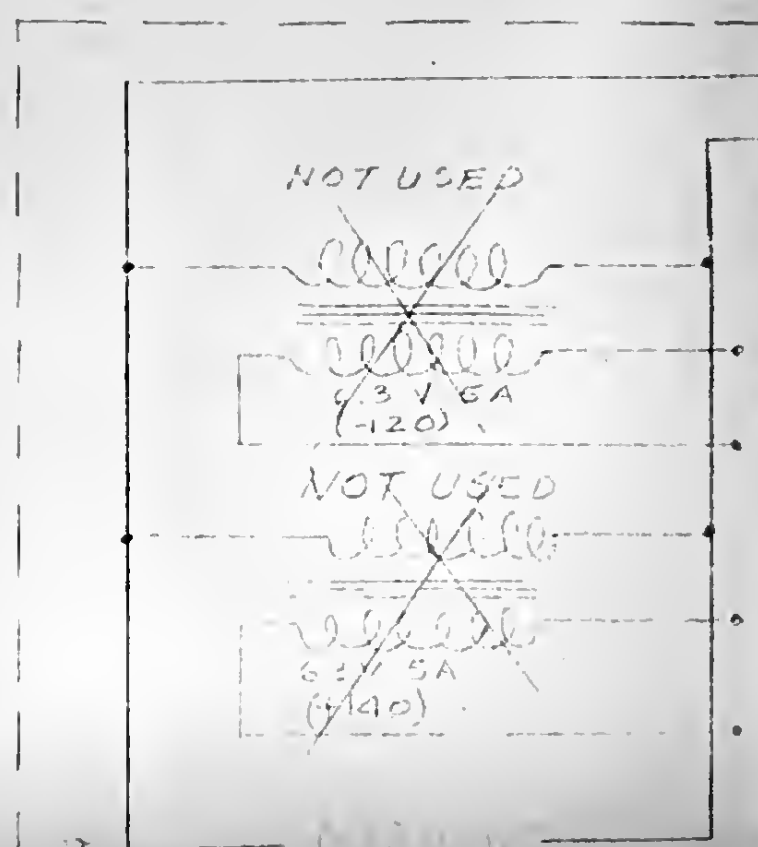
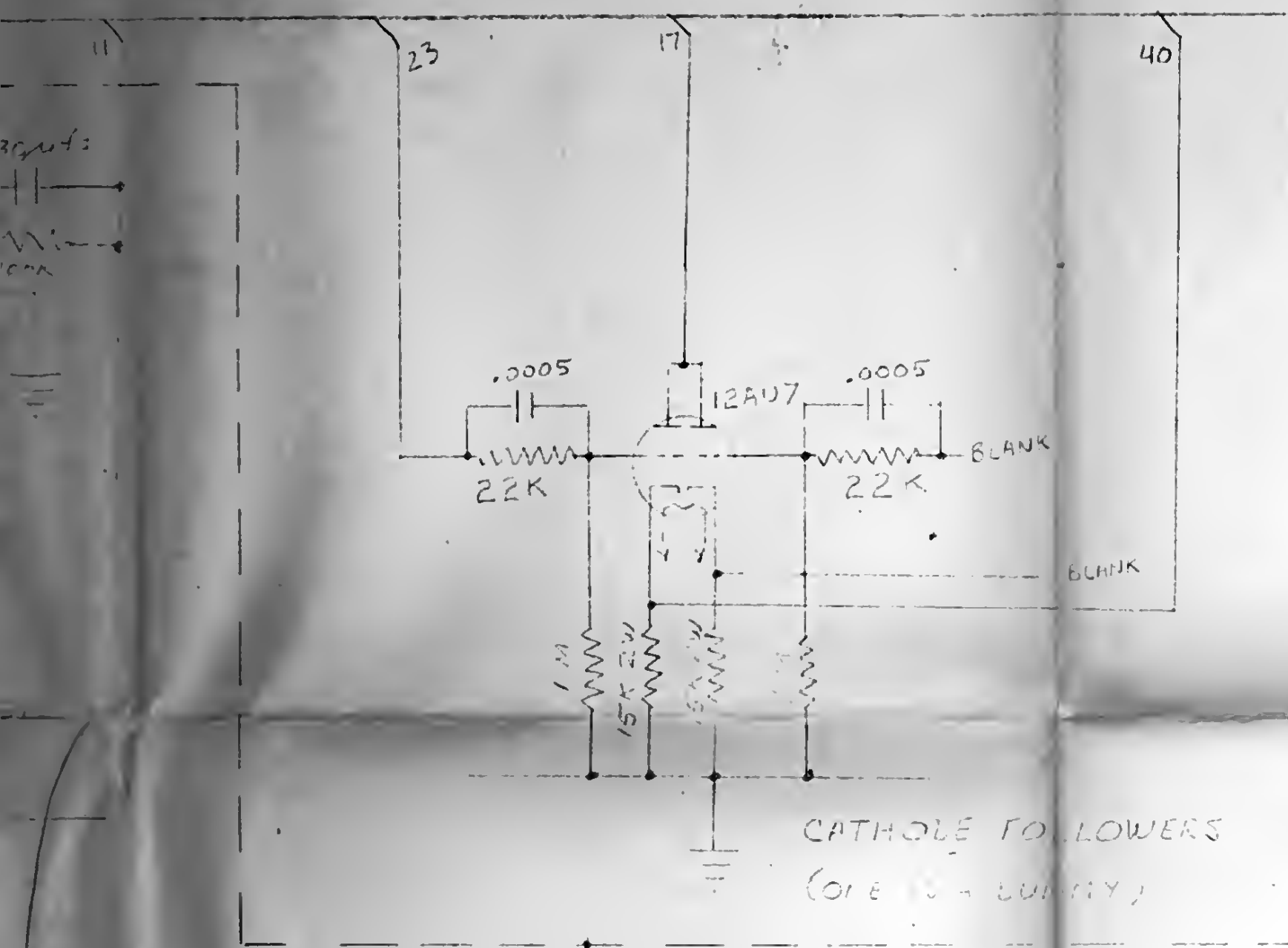
1. The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that proper record-keeping is essential for the transparency and accountability of the organization. This section also outlines the various methods used to collect and analyze data, ensuring that the information is reliable and up-to-date.

2. The second part of the document focuses on the implementation of the proposed changes. It details the steps involved in the transition process, from the initial planning phase to the final execution. This section also addresses the potential challenges that may arise during the implementation and provides strategies to overcome them.

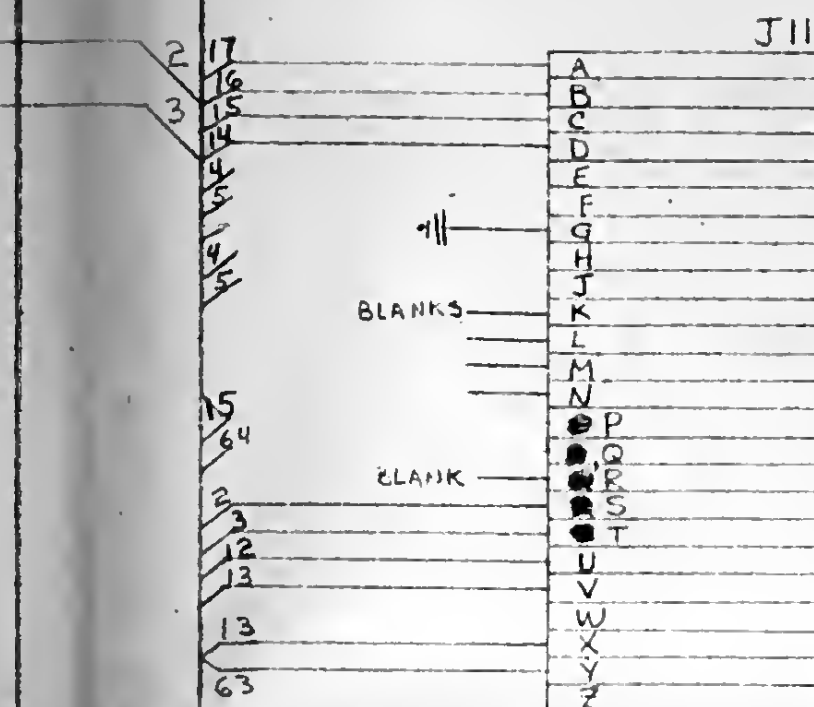
3. The third part of the document discusses the impact of the proposed changes on the organization's overall performance. It highlights the expected benefits, such as increased efficiency and cost savings, and provides a detailed analysis of the potential risks. This section also includes a timeline for the implementation of the changes and a list of the key personnel responsible for each stage of the process.

4. The fourth part of the document provides a summary of the findings and conclusions. It reiterates the importance of the proposed changes and the need for continued monitoring and evaluation. This section also includes a list of recommendations for future research and a final statement of the author's conclusions.





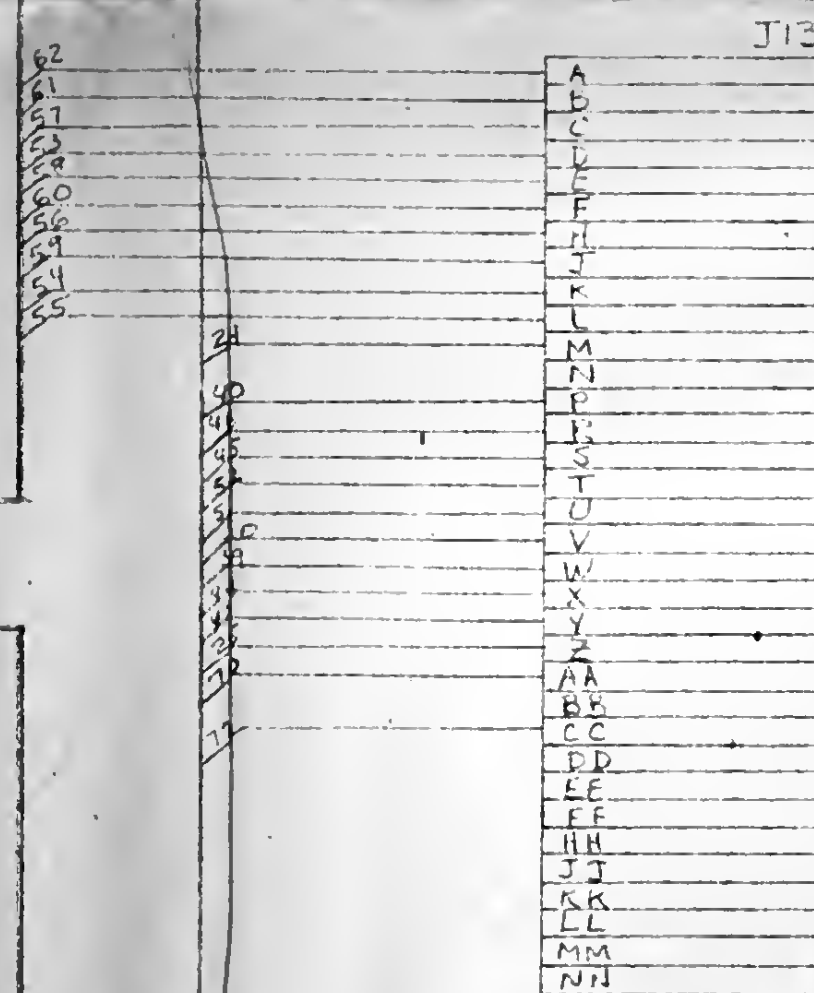
ALL FILS ON
THIS CIRCUIT
OUT -250V
SUPPLY
0.3 V 10 A.



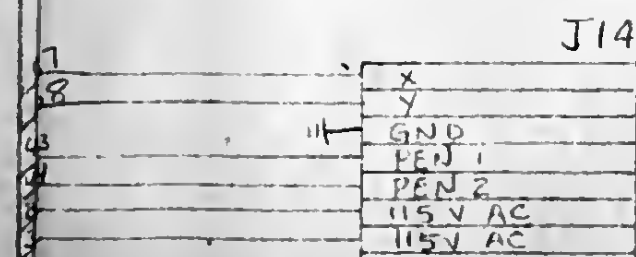
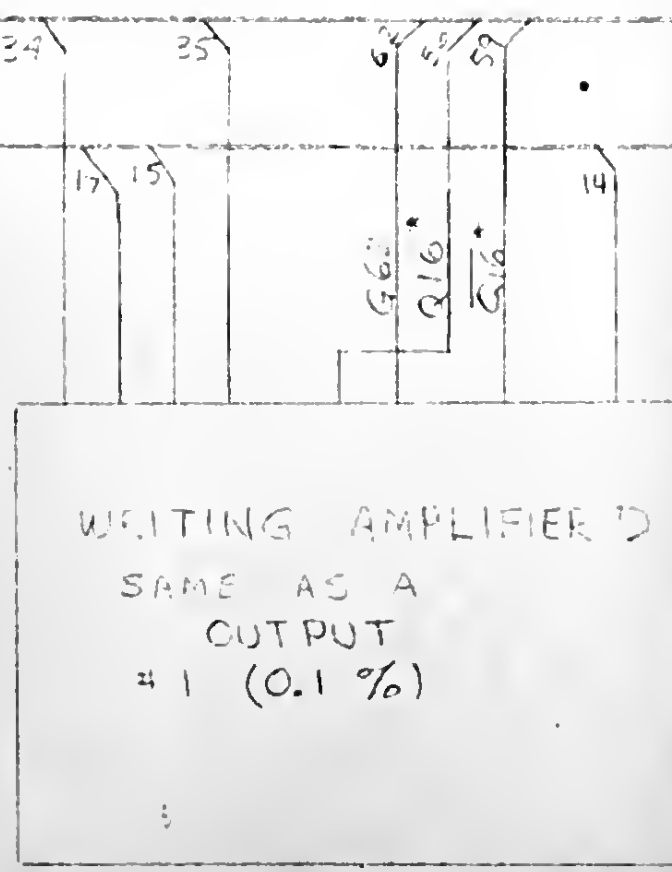
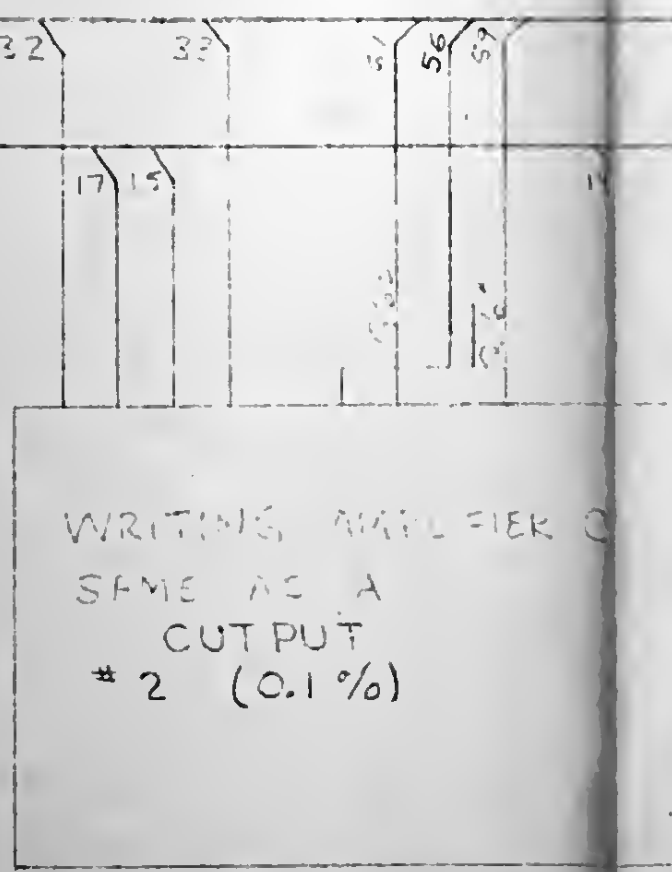
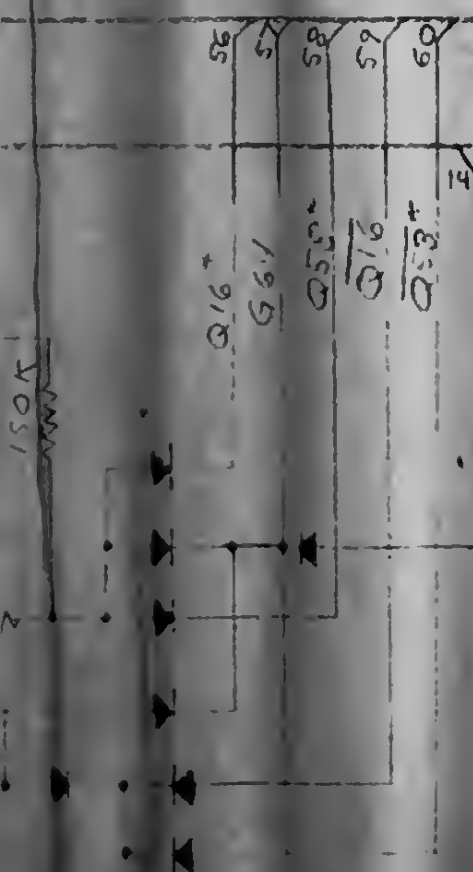
TO J4
INPUT-OUTPUT
UNIT



TO COAX
INPUT-OUTPUT
UNIT

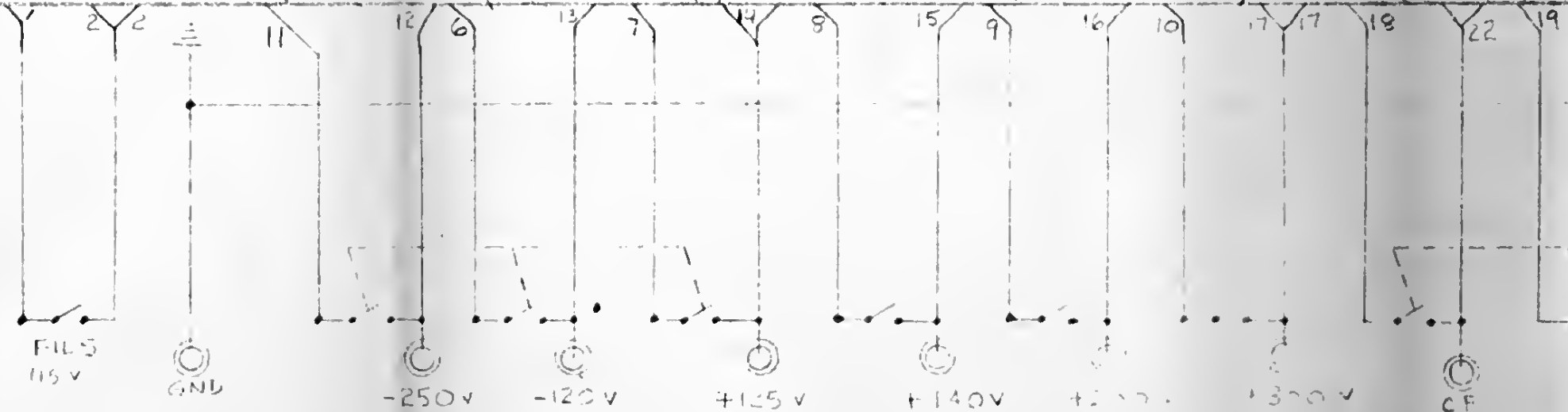
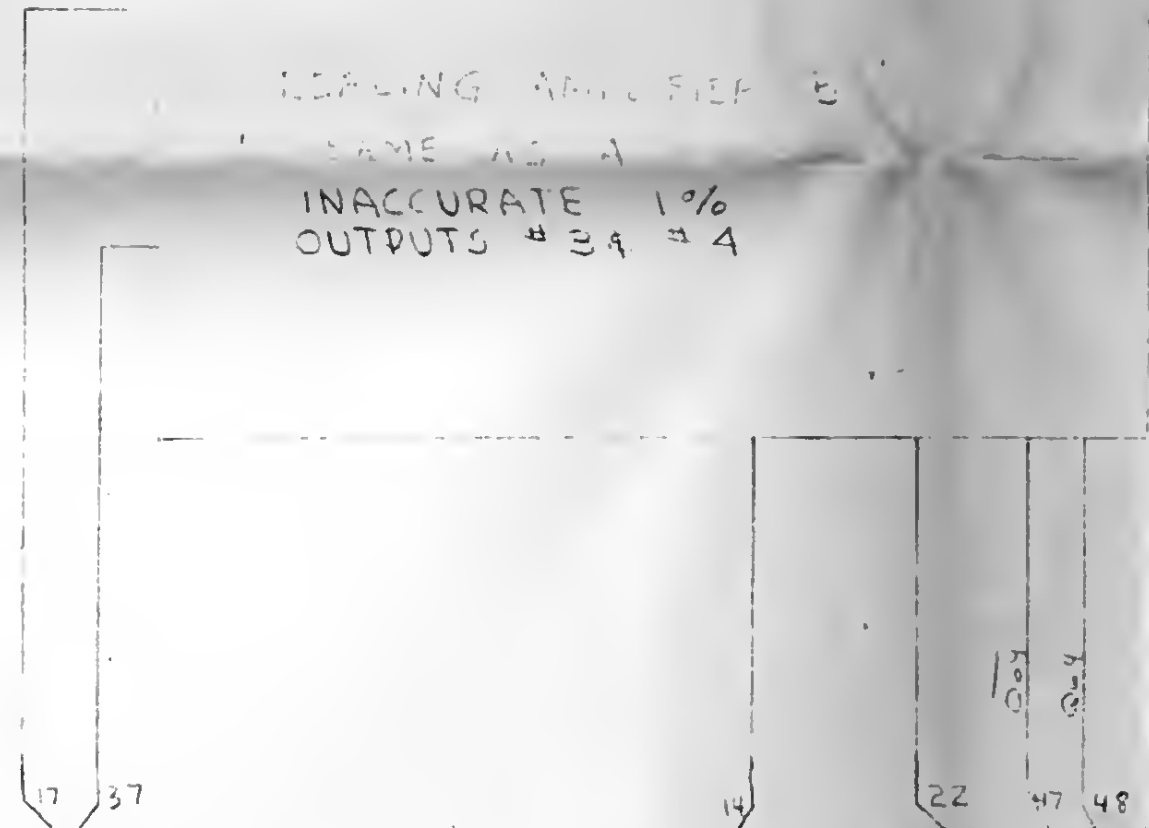
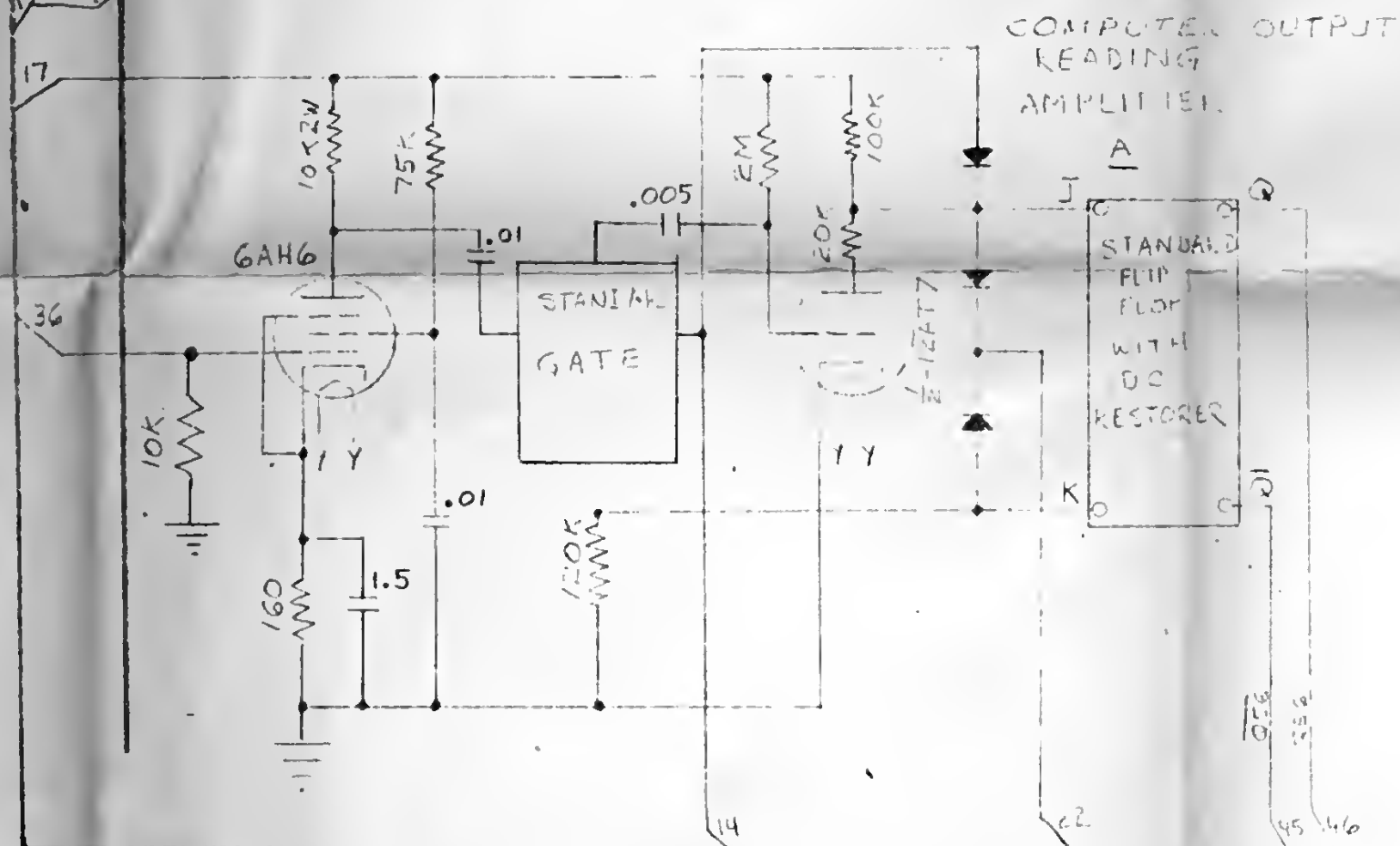
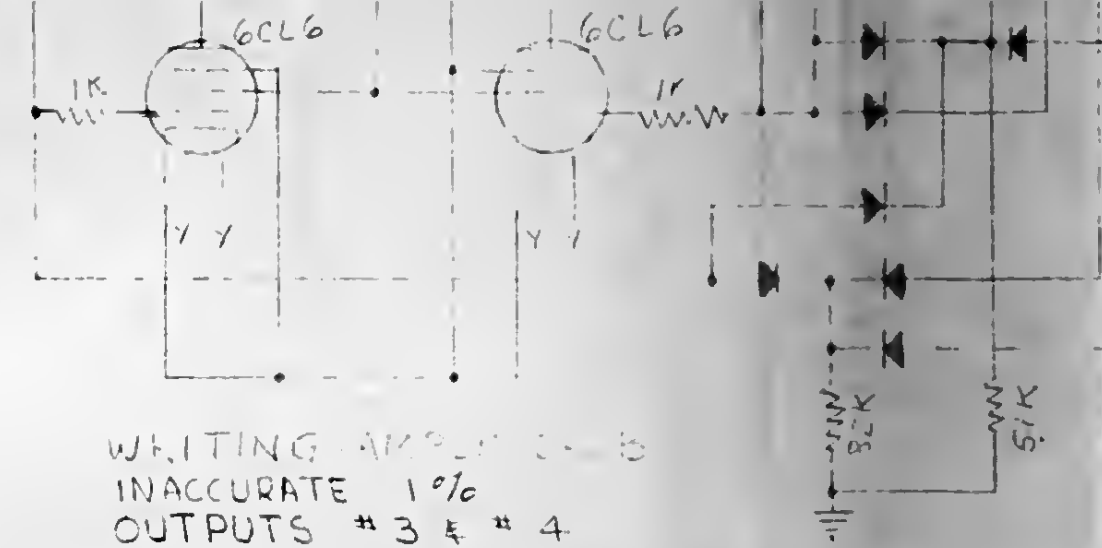
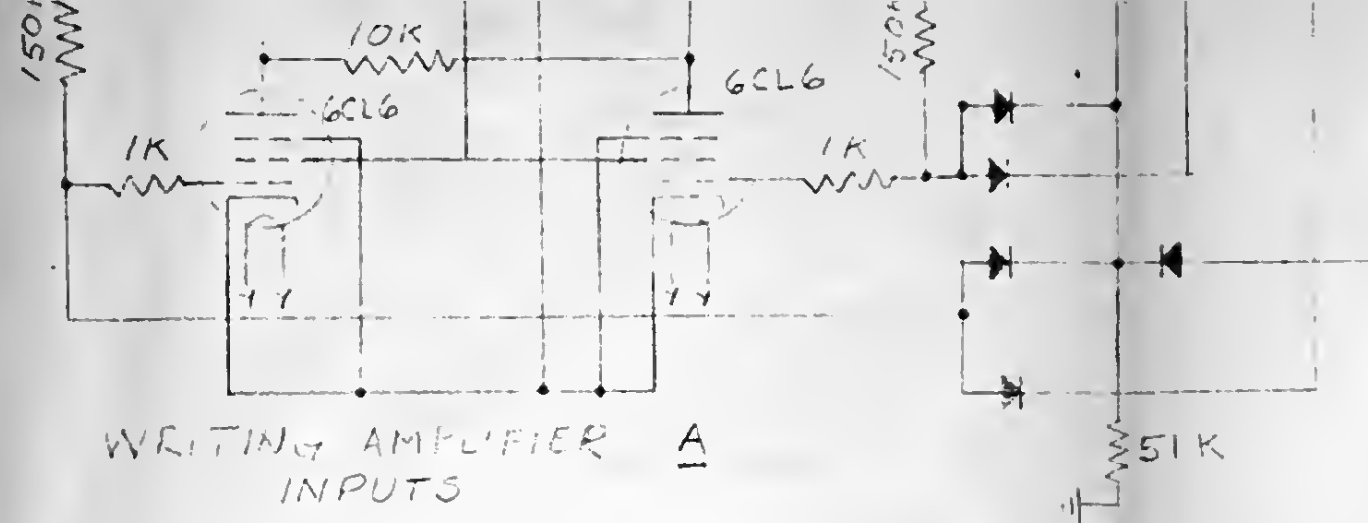
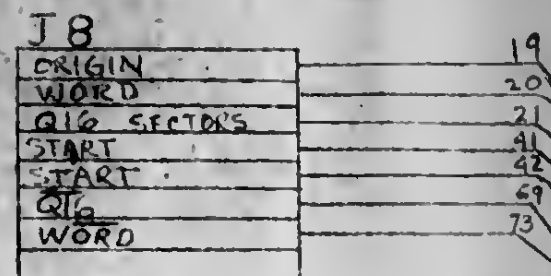


TO J2
INPUT-OUTPUT
UNIT



TO PLOTTING
BOARD

TO COMPUTER
JUNCTION BOX



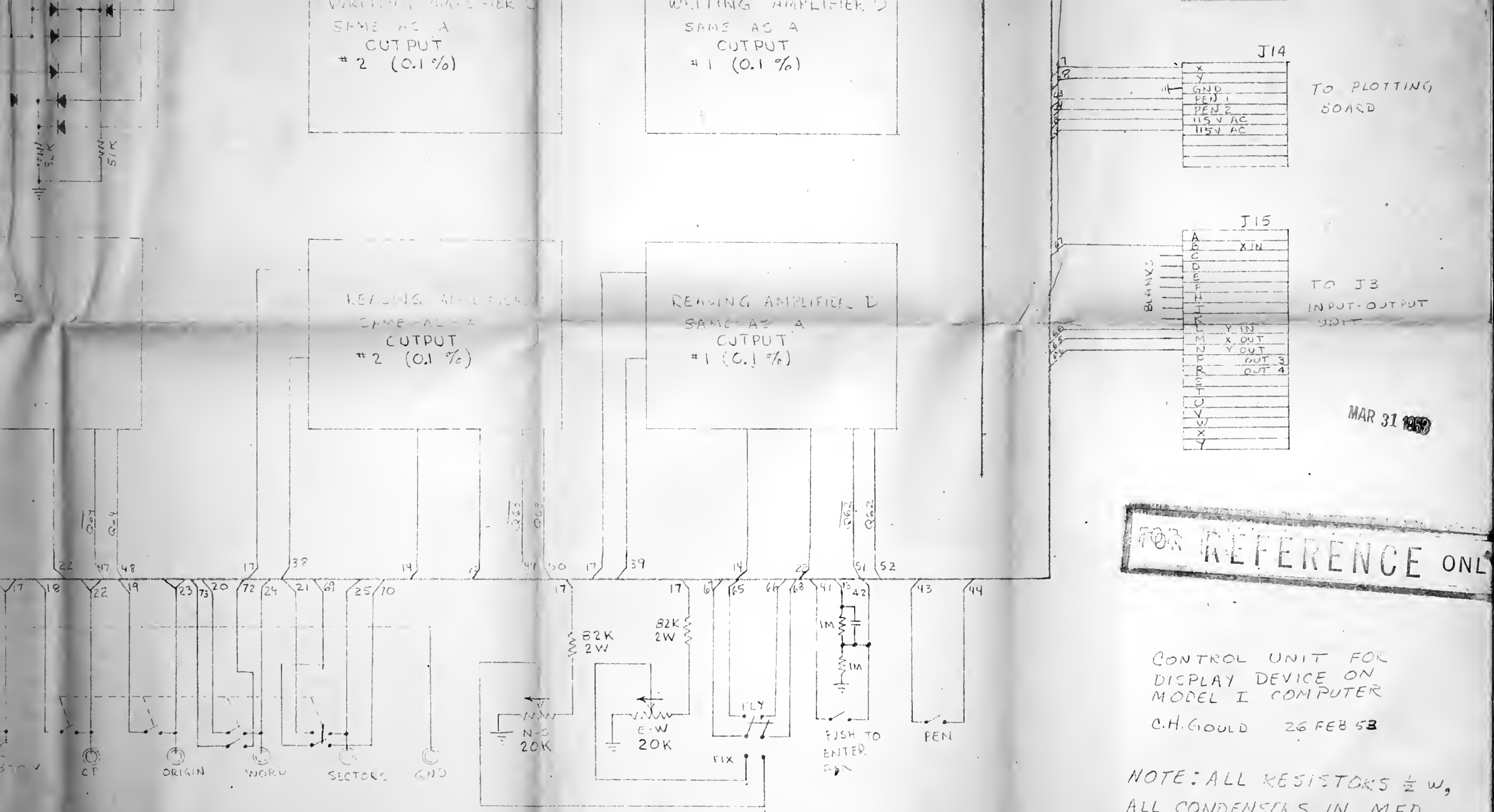


FIGURE I. SCHEMATIC OF CONTROL BOX

| SECTORS | ORDER BAND 1 | ORDER BAND 2 | ORDER BAND 3 | ORDER BAND 4 | ORDER BAND 5 | ORDER BAND 6 | ORDER BAND 7 | ORDER BAND 8 OR
NUMBER BAND 1 | NUMBER BAND 2 | NUMBER BAND 3 | NUMBER BAND 4 | NUMBER BAND 5 | NUMBER BAND 6 | SECTORS |
|---------|----------------------------|----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------------|-----------------|---------------|---------------------------------------|----------------|---------------------------|---------|
| 64 | | X 0,0,6 64F | d ₂ a 1,0,2 17E | ad ₂ 1,0,5 98F | d ₁ a 0,0,1 15T | | | | | | | | | 64 |
| 1 | ba 0,0,1 1T | ba 1,0,8 1F | ba 0,0,3 1E | ba 0,0,6 145F | | | | | | | | | | 1 |
| 2 | + 5,0,1 16T | cm 1,1,4 31E | ckS 2,0,7 114F | am 10,3,8 43F | | | | | | | | | | 2 |
| 3 | md ₅ 1,4,1 2T | d ₄ m 0,1,2 18E | ma 0,1,3 2E | bd ₄ 0,0,5 84F | d ₁ c 5,0,6 99F | d ₅ c 1,0,6 146F | | | | | | | | 3 |
| 4 | d ₃ m 6,3,7 36T | cd ₆ 1,0,5 17F | ca 0,0,2 55F | + 0,0,3 104F | am 10,6,8 179F | | | am 1-16,2,2 21E
ma 1-16,2,4 2F | | | | | | 4 |
| 5 | am 12,3,8 174F | wt 31,0,3 19E | + 0,0,3 3E | mc 5,4,6 32E | mc 1,4,3 85F | + 2,0,6 183F | + 0,0,6 162F | | | | 0.00000000000000 | | | 5 |
| 6 | md 2,4,1 3T | ad ₁ 2,0,5 56F | d ₆ a 7,0,7 105F | cd ₁ 2,0,7 128F | | am 0,6,5 147F | wt 12,0,6 115F | | X ₁₆ | | | | | 6 |
| 7 | | cm 15,2,2 22E | ma 0,4,3 4E | mc 15,2,4 3F | d ₃ a 3,0,3 18F | ma 0,4,5 163F | d ₂ a 2,0,5 116F | | X ₈ | | 0.00111111111111 | | OUTPUT 1 X _{n+1} | 7 |
| 8 | ma 2,3,8 41T | cm 15,2,2 | d ₄ a 3,0,7 86F | mc 15,2,4 | ad ₁ 0,0,8 148F | | | | X ₁₂ | | 2 ⁻⁴ | | | 8 |
| 9 | ma 0,4,1 17T | cm 15,2,2 | + 0,0,3 5E | mc 15,2,4 | + 0,0,6 164F | ckO 0,0,3 184F | | | X ₄ | | 1-2 ⁻⁷ | | | 9 |
| 10 | md ₃ 0,4,1 4T | cm 15,2,2 | md ₆ 3,5,5 7F | mc 15,2,4 | X 0,0,5 57F | X 13,0,4 100F | d ₁ a 6,0,3 129F | cm 0,6,5 149F | X ₁₄ | | 2 ⁻⁷ | | | 10 |
| 11 | - 3,0,1 18T | cm 15,2,2 | bd ₄ 0,0,3 6E | mc 15,2,4 | - 1,0,5 117F | bd ₄ 0,0,8 165F | | | 16 | COUNT #T | 0.00000000000000 | | OUTPUT 2 Y _{n+1} | 11 |
| 12 | d ₅ c 0,0,1 5T | cm 15,2,2 | + 0,0,3 19F | mc 15,2,4 | ma 0,3,7 150F | am 2,6,5 33E | wt 29,0,1 37T | - 0,0,6 44T | X ₁₀ | | | INPUT 1 | | 12 |
| 13 | | cm 15,2,2 | ma 0,5,3 7E | mc 15,2,4 | cm 1,6,3 26E | Aca 0,0,6 32F | X 1,0,3 87F | ma 0,4,8 166F | X ₂ | | X _p -X + Y _p -Y | | | 13 |
| 14 | d ₁ a 2,0,1 6T | cm 15,2,2 | d ₆ a 7,0,2 20F | mc 16,2,4 | bd ₂ 3,0,6 118F | ckO 1,0,1 43T | + 0,0,6 151F | d ₁ a 2,0,7 44F | X ₁₅ | | 2 ⁻⁴ +2 ⁻¹⁴ | INPUT 2 X | | 14 |
| 15 | | cm 15,2,2 | md ₈ 0,5,3 8E | mc 15,2,4 | ma 0,5,5 8F | ad ₅ 5,0,3 33F | - 0,0,7 106F | + 0,0,8 167F | X ₇ | | | OUTPUT 4 LIGHT | | 15 |
| 16 | bd ₁ 0,0,6 19T | cm 15,2,2 | ckO 0,0,3 27E | mc 15,2,4 | cm 1,3,1 34E | ma 0,4,5 152F | | ma 6,4,5 180F | 11 | | | INPUT 3 Y | | 16 |
| 17 | wt 31,0,1 44T | cm 15,2,2 | + 0,0,3 9E | mc 15,2,4 | + 0,0,5 9F | bd ₄ 3,0,6 85F | bd ₄ 3,0,7 107F | ma 0,2,7 168F | X ₅ | | 0.00111111111111 | | | 17 |
| 18 | X 0,0,1 7T | cm 15,2,2 | ckS 2,0,5 120F | mc 15,2,4 | - 0,0,3 153F | + 0,0,1 20E | + 0,0,7 45F | | 13 | COUNT #F | | INPUT 4 | | 18 |
| 19 | ckO 0,0,2 35E | cm 15,2,2 | ma 0,4,3 10E | mc 15,2,4 | ma 0,4,5 10F | d ₈ a 4,0,5 119F | + 0,0,8 169F | ckS 2,0,6 175F | X ₉ | | | OUTPUT 3 | | 19 |
| 20 | d ₅ a 0,0,1 21T | cm 15,2,2 | ba 1,0,3 154F | mc 15,2,4 | | | d ₅ a 0,0,3 46F | | X ₀ | | 0.00000001000111 | INPUT 5 | | 20 |
| 21 | | cm 15,2,2 | div 0,0,3 11E | mc 15,2,4 | div 0,0,5 11F | d ₅ c 7,0,5 66F | d ₂ a 4,0,6 108F | ba 0,0,4 170F | X ₁ | | | | | 21 |
| 22 | + 0,0,1 22T | cm 15,2,2 | d ₁ a 2,0,3 34F | mc 15,2,4 | d ₅ a 6,0,6 131F | | | | | | | INPUT 6 | | 22 |
| 23 | - 0,0,3 21F | ckS 0,0,6 155F | wt 26,0,4 171F | d ₅ a 5,0,7 123F | wt 28,0,5 176F | | | | X ₁₆ | | 1.00000111011110 | | | 23 |
| 24 | bd ₅ 4,0,8 23T | mc 16,4,2 28E | ma 10,3,5 79F | cd ₆ 15,0,4 4F | wt 32,0,4 181F | ma 15,4,6 177F | | | X ₈ | | | | | 24 |
| 25 | | mc 14,4,2 23E | bd ₂ 0,0,3 22F | cd ₈ 14,0,4 | + 1,0,5 120F | wt 32,0,4 156F | | | X ₁₂ | | | | | 25 |
| 26 | | mc 13,4,2 | + 0,0,3 35F | cd ₈ 13,0,4 | | wt 29,0,3 160F | | | X ₄ | | | INPUT 7 | | 26 |
| 27 | | mc 12,4,2 | d ₂ c 6,0,3 23F | cd ₈ 12,0,4 | ba 0,0,3 58F | + 0,0,5 109F | wt 24,0,2 158F | | X ₁₄ | | | | | 27 |
| 28 | | mc 11,4,2 | d ₅ a 0,0,1 36F | cd ₈ 11,0,4 | d ₇ a 2,0,6 121F | | | | X ₆ | | | | | 28 |
| 29 | | mc 10,4,2 | ad ₂ 4,0,5 59F | cd ₈ 10,0,4 | d ₄ a 6,0,7 110F | | | | X ₁₀ | | | | | 29 |
| 30 | + 16,0,4 37F | mc 9,4,2 | - 0,0,3 47F | cd ₈ 9,0,4 | ma 0,4,5 67F | + 1,0,5 132F | - 1,0,5 134F | d ₁ a 2,0,1 24T | X ₂ | | | INPUT 8 | | 30 |
| 31 | | mc 8,4,2 | ba 0,0,3 88F | cd ₈ 8,0,4 | | | | | X ₁₅ | | 0.00100101010111 | | | 31 |
| 32 | | mc 7,4,2 | ba 0,0,3 48F | cd ₈ 7,0,4 | X 0,0,4 68F | - 0,0,5 122F | | | X ₇ | | | | | 32 |
| 33 | | mc 6,4,2 | ad ₂ 0,0,6 89F | cd ₈ 6,0,4 | ba 0,0,7 135F | | | | X ₁₁ | | | | | 33 |
| 34 | + 0,0,1 25T | mc 5,4,2 | am 0,3,3 49F | cd ₈ 5,0,4 | bd ₄ 1,0,8 123F | | | | X ₃ | | | INPUT 9 | | 34 |
| 35 | div 0,0,1 8T | mc 4,4,2 | Aca 0,0,5 24F | cd ₈ 4,0,4 | d ₂ c 6,0,4 60F | + 0,0,6 90F | ad ₅ 1,0,6 136F | | X ₁₃ | | X _p -X - Y _p -Y | | | 35 |



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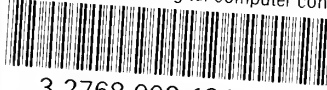
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